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# FINAL REPORT
# APPLICATION OF REMOTE SENSING FOR PLANNING PURPOSES

**May 1976 - July 1977**

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and

The University of Alabama
Department of Geology and Geography

in cooperation with

The Geological Survey of Alabama

Edited by
Travis H. Hughes
Department of Geology and Geography

Contractor
THE UNIVERSITY OF ALABAMA
University, Alabama 35486

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"Workshops in Remote Sensing"

For the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration

## CONTRIBUTORS

National Aeronautics and Space Administration:

John Bensko

Department of Geology and Geography:

Pamela Bloss

Robert Fambrough

Douglas Freehafer

Travis H. Hughes

Neal G. Lineback

Rex Price

Stephen H. Stow

Geological Survey of Alabama

Robert L. Barnett

James Drahovzal

Karen E. Richter

Donald D. Russell

Daniel Sapp*

*Presently with TVA

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Appendix

# AVAILABILITY, TYPES, AND SOURCES OF REMOTE SENSING IMAGERY, LABS, AND EQUIPMENT

Robert L. Barnett
Geological Survey of Alabama
P.O. Drawer "O"
University, Alabama 35486

## Introduction

Types of remotely sensed data are many and varied but, all are primarily dependent on the sensor platform and the kind of sensing system used. A sensor platform is the type of aircraft or satellite to which a sensing system is attached; each platform has its own inherent advantages and disadvantages. Table 1 outlines selected attributes of several current or recently used platforms.

A sensing system is any device(s) used to acquire imagery from which information of a given area may be extracted. Though sensing systems are highly varied, they may be divided into various operational categories such as cameras, electromechanical scanners, and radars.

## Cameras

Cameras are perhaps the most widely used and the most easily understood sensing system. They are characterized by a generally high degree of resolution, an operational range in the visible or near-visible wavelengths, a lens, and simultaneous recording of all the elements of a scene. Besides the many types of standard single-lens aerial cameras available, there are also multispectral cameras that take several simultaneous photographs of a single area. By using a different filter on each of the lenses, each photograph records the electromagnetic radiation in a different band of the spectrum. This allows the interpreter to distinguish very subtle differences between objects on a multispectral photograph that might be missed on a photograph produced from a broadband camera and film.

## Scanners

Scanners are essentially sensors that image by means of a moveable collector that oscillates while the platform provides forward motion. The two most common scanner types are the multispectral scanner (MSS) and the infrared scanner. The MSS collects electromagnetic radiation in several very narrow spectral bands by

| Platform | Data Characteristics | Approximate Altitude | General Applications |
|---|---|---|---|
| LANDSATS 1 and 2 | Small scale<br>Large areal coverage<br>Low resolution<br>Multispectral coverage<br>Repetitive at same sun angle | 920 km<br>(495 n. mi.) | Small-scale synoptic mapping of gross geology, land use, soils, vegetation, and floods. Update of broad configurational changes in land/water interfaces. Lake and strip-mine inventory. Lineament mapping. Marine and fresh-water turbidity plume delineation. (On-going program.) |
| Gemini, Apollo, Skylab | Small scale<br>Large areal coverage<br>Low resolution<br>Constant sun angle over large area<br>Some multispectral coverage<br>Some repetitive coverage | 160-400 km<br>(100-250 n. mi.) | Relatively the same as for Landsat though with limited repetitive coverage. Skylab had higher resolution capability and greater number of sensors. (Skylab, Gemini, and Apollo programs have ended.) |
| High-altitude Aircraft (U-2, RB-57F) | Moderate scale<br>Moderate resolution<br>Moderate areal coverage<br>Multispectral coverage<br>Greater variety in sensing systems<br>Some repetitive coverage during ongoing Landsat projects-otherwise specific missions | 18,000-21,000m<br>(60,000-70,000 ft.) | Same as Landsat at greater resolution; therefore more detailed mapping and inventory is possible. Detailed planimetric maps. Urban land-use analysis. (On-going program.) |

Table 1. Sensing platforms, data characteristics, and applications in Alabama.
Source: Remote Sensing of Earth Resources in Alabama, Geological Survey of Alabama, in press.

| | | | |
|---|---|---|---|
| Medium-altitude Aircraft (NP3A, NC130B, B-23, Mohawk) | Large scale<br>High resolution<br>Small areal coverage<br>Greater variety in sensing systems<br>Specific missions | 6,100-9,150 m<br>(20,000-30,000 ft.) | Large-scale mapping and inventory of all types. Limestone terrane studies. SLAR structural analyses. Engineering geology studies. Hydrologic studies. Crop disease detection. (On-going program.) |
| Low-altitude Aircraft (De Havilland Beaver, Cessna 310, Beech C-35) | Very large scale<br>Very high resolution<br>Very small areal coverage<br>Possible multispectral coverage<br>Greater variety of sensing systems<br>Specific missions | 300-3,000 m<br>(1,000-10,000 ft.) | All the above at very large scales and in great detail. Topographic mapping. Highly detailed urban land-use analysis. Vegetative species differentiation and crop disease detection. Specific problems of all types. (On-going program.) |

Table 1 - continued

scanning the earth's surface. Landsat uses an MSS that collects data in four bands; band 4 is blue spectral, band 5 is red spectral, and bands 6 and 7 are infrared. These can be combined to make a color composite. Skylab's MSS produced images within 13 spectral bands.

The infrared scanner is one of the most common devices used in remote-sensing studies. During the daylight hours infrared radiation is partly reflected and partly absorbed by a given object. This absorbed radiation is later emitted by the object and can be recorded at night due to its longer wavelength and the absence of reflected infrared radiation from the sunlight. Thermal infrared imagery records emitted infrared radiation and should not be confused with infrared photography, which records only reflected infrared radiation.

## Radars

Radar imagery is rather unique among remotely sensed data because of its physical characteristics and its applications. SLAR (side-looking airborne radar) is generally used to obtain a fairly precise image of the ground surface for geologic purposes. Radars provide their own illumination by using self-generated radio waves that penetrate cloud cover, haze, and low to medium-height vegetation to obtain a clear, high-resolution image.

## Films

A specific kind of film, within an aerial camera, will record electromagnetic radiation and produce a specific type of aerial photograph. Films can produce an image from wavelengths as short as near-ultraviolet, up through the visible light spectrum (blue, green, red), to include wavelengths as long as near-infrared. The inclusive range of recording radiation on film is determined, on the lower end, by the optical limits of glass (0.36 um) and on the upper end by the infrared sensitivity of the film (maximum of about 1.1 um). Table 2 lists, describes, and gives the general applications of the more common kinds of films for aerial cameras.

## Sources of Imagery

The following is a partial listing of governmental agencies that are actively engaged in generating and/or storing/cataloging remotely sensed data. In order to obtain coverage of a given area, users should directly contact the agency that is most likely to fulfill their needs. In any correspondence, the area description should be as detailed as possible; all of the following items should be included:

Table 2. Selected characteristics of aerial fims.

| Film Type | Film No. | Sensitivity | Description and Applications |
|---|---|---|---|
| Plus-X Aerographic | 2402 | Panchromatic (with extended red) | Medium speed for aerial mapping and reconnaissance. |
| Tri-X Aerographic | 2403 | | High speed for aerial mapping and reconnaissance under low levels of illumination. |
| Double-X Aerographic | 2405 | | Medium- to high-speed, standard film for mapping. |
| Panatomic-X Aerial | 3400 | | Intermediate-speed, high-contrast, medium- to high-altitude reconnaissance film, suitable for small-negative format. |
| Plus-X Aerial | 3401 | | Medium-speed, high-contrast, fine-grain, medium- to high-altitude reconnaissance film. |
| High-Definition Aerial | 3414 | | Slow-speed, high-definition film for high-altitude reconnaissance. |
| High-Definition Aerial (Ultra-thin base) | 1414 | | Ultra-thin film similar to 3414. |
| Infrared Aerographic | 2424 | Infrared | Black-and-white film for reduction of haze effects, water location, vegetation surveys, and multispectral aerial photography. |
| Aerochrome Infrared | 2443 | | False-color reversal film for vegetation surveys and other special purposes. |
| Aerochrome Infrared (Thin base) | 3443 | | Thin film similar to 2443. |
| Aerocolor Negative | 2445 | Color | High-speed color negative film without intergral masking for mapping and reconnaissance. |
| Aerochrome MS Film | 2448 | | Color-reversal film for low- to medium-altitude aerial mapping and reconnaissance. |

Table 2 - continued

| | | | |
|---|---|---|---|
| Aerial Color | SO-242 | Color | Slow-speed, high-resolution color-reversal film for high-altitude reconnaissance. |
| Aerial Color (Ultra-thin base) | SO-255 | | Ultra-thin film similar to SO-242. |
| Ektachrome EF Aerographic | SO-397 | | High-speed, color-reversal film for aerial mapping and reconnaissance. |

Sourse: Eastman Kodak Company, 1973

latitude and longtitude, state, county, location relative to a town, city, or major highways, etc.

U. S. Geological Survey
User Services Center
EROS Data Center
Sioux Falls, South Dakota 57198

NASA Aircraft Photography:

Standard image sizes are 70mm, 5" wide, 10" wide.

| Black and White Formats | Color Formats |
|---|---|
| Film positives (max. size 9" x 18") | Positive transparencies (max. size 9" x 18") |
| Film negatives (max. size 9" x 18") | Paper print (max. size 36" x 36") |
| Paper print (max. size 36" x 36") | |

Aerial Mapping Photography:

Standard image size is 9" x 9".
Enlargement sizes are 2x, 3x, 4x.

Black and White Formats

Film positives
Film negatives
Paper prints
Photo indexes

LANDSAT (formerly ERTS):

Bands available - 4, 5, 6, 7.

False Color Composites

| Image Size | Scale | Format |
|---|---|---|
| 7.3 in. | 1:1,000,000 | Film positive |
| 7.3 in. | 1:1,000,000 | Paper |
| 14.6 in. | 1:500,000 | Paper |
| 29.2 in. | 1:250,000 | Paper |

Black and White

| Image Size | Scale | Format |
|---|---|---|
| 2.2 in. | 1:3,369,000 | Film positive |
| 2.2 in. | 1:3,369,000 | Film negative |
| 7.3 in. | 1:1,000,000 | Film positive |
| 7.3 in. | 1:1,000,000 | Film negative |
| 7.3 in. | 1:1,000,000 | Paper |
| 14.6 in. | 1:500,000 | Paper |
| 29.2 in. | 1:250,000 | Paper |

Color Composite Generation

| | | |
|---|---|---|
| 7.3 in. | 1:1,000,000 | Printing master |

All aerial coverage generated by the District Water Resources Branch Office of the U. S. Geological Survey, Tuscaloosa, Alabama, is now being retained by the Geological Survey of Alabama.

NASA, Earth Resources Office, Code EF02, Marshall Space Flight Center, Alabama 35812, maintains a Remote Sensing User Lab. Interested parties should contact John Bensko for information and coordination.

U. S. Department of Agriculture
Agriculture Stabilization and Conservation Committee (formerly ASCS)

County offices within each state maintain individual photographs and photo indexes of their respective counties. Orders must be placed through local offices for coverage desired. Standard image size is 9" x 9" and the scale is 1" = 330'.

Tennessee Valley Authority
Maps and Surveys Branch
311 Broad Street
Chattanooga, Tennessee 37401

Available coverage consists of black and white prints, for parts of north Alabama, flown since 1960 at 1:24,000 scale, some coverage during the 1940's at 1:36,000 scale, and small area, special interest projects at various scales. Diversity of coverage makes a single index for general distribution impractical.

National Ocean Survey
Department of Commerce (NOAA)
Washington Science Center
Rockville, Maryland 28052

Standard image size is 9" x 9".
Enlargements are available for color prints, black and white prints, and positive transparencies; 2x, 3x, 4x sizes.
Photo index sheets at 1:250,000 scale are available.

| Black and White Formats | Color Formats |
|---|---|
| Panchromatic prints | Natural color prints |
| Infrared prints | Color infrared |
| Copy negatives | Positive transparencies |
| Film positives | |

Geological Survey of Alabama
P.O. Drawer "O"
University, Alabama 35486

Various types of coverage for the state of Alabama are available for study in the Remote Sensing User Lab at the Geological Survey of Alabama. Available standard format coverage and generating agency is listed in Appendix A of this publication. In addition, Landsat coverage and several special interest areas such as the Piedmont area, Coastal Alabama, portions of the Tennessee Valley area, and the Alabama oil fields are on microfilm and can be viewed using the Eros Browse File. Although materials are not sold, investigators are urged to make use of the materials and equipment in the user lab any time between 8:00 a.m. and 5:00 p.m., Monday - Friday.

# A Technique for Superimposing Landsat Images on 1:250,000 Scale Maps

Neal G. Lineback

There are several types of sophisticated equipment available to the potential Landsat user that can enhance the imagery and assist in inventory and analysis. Most of the equipment, however, is unavailable or at least somewhat inaccessible to most users.

Some research efforts have gone into the development and use of unsophisticated and commonly available equipment and techniques to accomplish in-house inventories using Landsat data. In fact, some of the techniques are compatible with other types of satellite and high altitude photography.

Color-additive viewers and density slicers certainly add to the usability of satellite data, however, the exorbitant costs of this equipment are in excess of the total budgets of many potential users. A considerable amount of experimentation is necessary to efficiently use the equipment, after which repetition of experiments is difficult at best and impossible in some cases. The utility of the two machines, then, must be weighed against their high costs, the nonrepetitiveness of experiments, the cost and time of travel necessary to gain access, and, in the case of the color-additive viewer, the inability of varying scales.

Other even more sophisticated equipment involving the use of computer compatible tapes and scanners are in use, but only by a limited number of academic project groups, private and public contractors and agencies of the federal government. Again, all of these are

not practical for use by most small and moderate users.

What options, then are open to those of us who periodically need to use limited amounts of satellite data? Essentially, we are left with two alternatives: 1) examining the data with the naked eye or 2) enlarging and enhancing it using locally available equipment. The remainder of this paper will discuss the latter alternative.

Copies of Landsat images are available in four bands (4, 5, 6, and 7) and a false color composite of the bands. Band 7 is best in distinguishing water interfaces with land; Bands 5 and 6 and the color composites appear best for geology, land use and biology signatures.

The images themselves come in 9"x9" positive transparencies, 9"x9" prints, 70 mm slides and color composites (mozaics) for individual states and for the United States. The 9"x9" transparencies and prints (either individual bands or false color composites) offer good possibilities for enlargement and enhancement--with a small amount of readily available equipment.

An overhead projector can provide considerable enlargement of the transparencies, although correct registration and precise scale changes provide problems not easily overcome by use of the overhead. Likewise a 70 mm slide or "lantern" projector can be used to enlarge the 70 mm slides, however, again precise scale changes have to be made by moving the entire projector back and forth.

After a considerable amount of work on projects delimiting forestland/cleared land interfaces for the Alabama Geological Survey, NASA and, later, the U.S. Forest Service, I learned several

"short cuts" for enhancing Landsat data. Essentially, a 35 mm camera and projector with a zoom lens are two pieces of equipment which are available to nearly everyone and which can offer some good enhancement opportunities.

One of the easiest procedures to enlarge an image without excessive distortion and yet be register to a map of another scale is as follows: 9"x9" transparencies (single band or false color) can be placed on a light table under a 35 mm camera mounted on a copy stand. Ectachrome or Kodachrome film may be used, however, the blue case of the Ectachrome appears to enhance the single band shots, while Kodachrome seems more suitable for false color. The camera is adjusted so that the frame is filled and the photo taken with backlight only. The mounted 35 mm slides can then be used in the 35 mm projector.

The projector is positioned in a manner such that the image is projected onto a flat wall surface. The scale can be varied depending upon the resolution of the specific Landsat image and the capabilities of the zoom lens on the projector. A map at the desired scale can be mounted on the wall and the image in the projector registered to it. Herein arises a problem inherent in all ERTS imagery, that is, random distortion. The problem cannot be totally resolved, however, continued reregistration of the image within the work area of the map can increase the accuracy.

The map scale can be varied, as previously mentioned, using the zoom lens of the projector. There are, however, certain limitations imposed by the imagery resolution. From a scale of 1:1,000,000 to 1:250,000 the resolution is good. Scales as large as 1:62,500

or 1:24,000 present some resolution problems and overall benefits do not necessarily increase proportionally. Optimally, 1:250,000 appears to be the best scale on which to obtain the greatest image clarity.

Several variations of the methodology above can be used. Light filters both on the camera and/or the projector can help enhance certain characteristics. The use of different film for copying the images will change the signatures and enhance them.

Such inexpensive methodologies allow the sometime user of satellite photography without access to expensive enhancement equipment a considerable amount of utility. What is needed is more such methodologies.

# Use of Landsat Images in Regional Land Use Studies

Neal G. Lineback
Department of Geography
The University of Alabama

Over the past ten years planning agencies, politicians, federal and state regulatory agencies and private industry have realized a distinct need for geographic inventories at a regional level. New EPA regulations concerning air and water quality and 201 requirements for environmental assessments have touched nearly everyone dealing with land use and imposed upon them the need to recognize on-going, as well as potential, impacts of activities affecting the environment.

Frequently, the data necessary to the recognition of environmental impacts have been available on the local scale through the use of field recognizance and SCS photography. Regional land use, however, and the associated regional impacts of activities affecting the environment have only recently been recognized as requiring intensive study. Channelization of a stream, clear-cutting and row crop agriculture and resulting siltation are examples of activities that may have regional consequences.

Landsat imagery offers three distinct and valuable assets: 1) the synoptic view allows the visual recognition of broad spatial patterns which can seldom be obtained through conventional photography; 2) the repetitive coverage on a regular basis allows seasonal comparisons of change; and 3) the computer-compatible tapes allow rapid map generation and analysis of land use, geology, vegetation, and atmospheric changes. All three of these characteristics

are not available through any other source, and Landsat is considered to have no substitutes at present.

There are five problems, however, associated with the use of Landsat data which have been expressed by some users: 1) the data have a lower resolution than most other conventional photography; 2) although the repetitive coverage is scheduled for every eighteen days, atmospheric conditions have negated many of the advantages of the eighteen-day cycle; 3) there has been a lag time of several months before new data have been processed and made available to potential users; 4) there has been a misconception among both potential and present users that sophisticated equipment is necessary for utilization of the data; and 5) the sophisticated, and sometimes unnecessary terminology has effectively lengthened the education time for some potential users.

The 70mm and 9x9 positives and the 9x9 and 30x30 prints or composites are the data with which most users are familiar. These data may be used with or without enhancing equipment, but for most uses some sort of enhancement is desirable. As will be related later in the program, however, the equipment need not be sophisticated.

By enlarging the images to 1:500,000 or 1:250,000 three major categories of signatures can be determined with the naked eye: land use, biological and geologic/hydrologic aspects. Broad and general land use patterns are easily discernable, particularly plowed, open pasture, forest and urban land. Biological differences, specifically forest types, are also easily recognized. Geological and hydrological aspects of the landscape, particularly extreme features such as ridges and water, including

flooded areas, usually have strong and identifiable signatures.

At 1:250,000 scale, the first level and part of the second level of the National Land Use Classification can be mapped:

Urban and built-up
Agricultural
    Cropland and Pasture
    Horticulture areas (exceeding 10 acres)
Forestland
    Deciduous forest
    Coniferous forest
    Brushland
Water
    Streams
    Lakes
    Gulfs
    Bays
    Estuary
    Flooded
    Wetlands
Bareland
    Beaches
    Strip mines (over 25 acres)

# LAND USE AND IMPERMEABLE COVER IN SHADES VALLEY

Robert Fambrough and Douglas Freehafer

Department of Geology and Geography
University of Alabama
University, AL 35486

High altitude U-2 and satellite Skyland imagery was used to determine land cover in the Shades Valley area and ultimately determine percent impervious cover. The different categories for the various types of land cover were adapted from the Geological Survey Professional Paper 964, "A Land Use and Land Cover Classification System for Use with Remote Sensor Data," and the ones used in the report are as follows:

LEVEL I
Urban or Built-Up Land
    LEVEL II
    Residential
    Services
    Transportation
    Industrial and/or Commercial
    Mixed Urban
    Other
Agricultural Land
Forest Land
Barren Land

Interpretations of the various categories were based on patterns, tones, textures, shapes and site associations aided by knowledge of the area, available topographic maps and close inspection of the original transparencies on points using a binocular microscope.

The U-2 images had a much wider color variation and greater contrast than the Skylab images. The Commercial and Industrial

land cover was discerned by a very bright or almost white area of large buildings and parking lots. Transportation facilities were determined through topographic map associations and close inspection of the transparencies. Service areas were similar to Industrial and Commercial Lands but were differentiated by either knowledge of the area or topographic maps. Residential land cover appeared as a mottled light and dark area. The Mixed Urban Land composed of Commercial and Residential Intermixtures appeared on the imagery as a much more dense and lighter area than the Residential cover, but darker than the bright appearance of Industrial and Commercial Land. The golf courses and open land of the Other Urban category were interpreted by examination of transparencies and knowledge of the area as well as a distinctive texture of golf course fairways and other open areas. The contrast and colors of the U-2 imagery made it much easier to distinguish the various Urban Lands than the Skylab image which was taken through haze and displayed a variety of blues and white.

Since the photos were taken in December, 1973, the Forest Land had a winter foliage as hardwood trees were without leaves. But the evergreens and conifers showed as a medium to dark red color. On the Skylab images the nearly black or very dark areas were interpreted as Forest Land. Agricultural Land was indicated by a bright red generated by growing plants on the U-2 images but were not discernible in the blues of the Skylab imagery. Barren Land was interpreted where strip mines or timbered forests were distinguished by textures and topographic map associations.

For the Shades Valley area, two different land cover interpretive maps were constructed. One was constructed using information read from the U-2 images and the other utilizing the Skylab imagery. The different land cover maps were interpreted by two different individuals; one worked with the U-2 and one with Skylab data so that classification standards would not be confused from one image to the next.

To find the percent impervious cover from the land cover data, one would first need to know the average percent impermeable cover in each of the classification categories. With this known, the area of impervious cover may be calculated and then divided by the total area of the basin; this would yield the percent impervious cover.

There are discrepancies in the results obtained from the U-2 and Skylab images, but the data correlates in many respects. The railroad yards at Irondale were interpreted with a larger area in the U-2 data but urban transportation is otherwise equivalent. Smaller schools and religious institutions were observed in the U-2 interpretations and omitted in the Skylab due to poor resolution, and the U-2 data exhibits a larger Urban Services land cover. Likewise, Barren Land was easily detected in portions of the U-2 images and was indistinguishable in the Skylab photograph. The highlight areas of the Skylab images had indistinct margins while the margins were sharp on the U-2 slides. This resulted in a larger area of Industrial and Commercial Land in the Skylab data than in the U-2 data.

The greatest differences in the data involve the Urban Residential, Urban Mixed and Forest Land. The numerical differences are greatest in the Forest and Urban Mixed categories and least in the Urban Residential category. Portions of the Forest Land of the U-2 were apparently interpreted as Urban Residential on the Skylab images and the Urban Mixed of the Skylab imagery was interpreted as Urban Residential on the U-2 data.

There are several possible explanations for this result. As stated before, the U-2 imagery appeared to have a much higher quality of contrast and resolution. This may stem from the fact that the U-2 images were taken at a lower altitude in much better weather than the Skylab images. The lack of colors in the Skylab images was due to the effects of a very hazy, humid day, thus dulling the colors and decreasing the clarity of the image. Resolution was probably also lost in transferring the transparencies to slides due to the focusing difficulties and general loss of tolerance in the film and camera. Human error and incomplete criteria for interpretation are also factors which decreased accuracy. Contrast and resolution could be saved if one-thirty-five millimeter slides had been furnished as originals by the EROS Data Center.

The data for the percent impervious cover was derived partially from Leopold (1968) but is incomplete. Residential Land has a relatively low value due to interpreting the category as low density with the high density residential included in Mixed Urban Land. The percent impervious cover and area of impervious

cover for each category are shown for sections of the study area and the entire area in Table 1. There is a 10 to 15 percent discrepancy in the total percent impervious cover, but this could be resolved only by more accurate interpretation resulting from extensive field work.

## Reference Cited

Leopold, L. B., 1968, Hydrology for Urban Land Planning; U. S. Geological Survey, Circ. 554, 18 p.

TABLE 1

TOTAL STUDY AREA

| | U-2 | | | SKYLAB | | |
|---|---|---|---|---|---|---|
| | % IMP. COVER | AREA ($KM^2$) | IMPER. AREA | % IMP COVER | AREA ($KM^2$) | IMPER. AREA |
| URBAN LAND | | | | | | |
| Residential | 40 | 62.76 | 25.10 | 40 | 78.61 | 31.44 |
| Services | 40 | 1.50 | 0.60 | 40 | 0.36 | 0.15 |
| Transportation | 60 | 2.87 | 1.72 | 60 | 1.99 | 1.20 |
| Industrial and Commercial | 90 | 5.96 | 5.36 | 90 | 11.73 | 10.56 |
| Mixed | 80 | 13.80 | 11.04 | 80 | 39.47 | 31.58 |
| Other | 10 | 3.42 | 0.34 | 10 | 0.67 | 0.07 |
| AGRICULTURAL LAND | 5 | 2.02 | 0.10 | 5 | -- | -- |
| FOREST LAND | 5 | 141.41 | 7.07 | 5 | 97.54 | 4.88 |
| BARREN LAND | 3 | 3.81 | 0.11 | 3 | 2.85 | 0.09 |
| TOTAL | 21.65 | 237.55 | 51.44 | 34.29 | 233.22 | 79.97 |

# REMOTELY SENSED IMAGERY FOR FLOOD HAZARD MAPPING

By

Stephen H. Stow
Department of Geology and Geography

University, AL

The potential dangers and costs of unwise development of flood plains are very great. In 1970, Todd reported that the annual loss to flooding in this country often exceeds $1.5 billion. The cost of flood hazard mapping can be very great, often exceeding thousands of dollars per kilometer of river. Urban development is increasing and flood plains represent an extremely attractive area for development due to their topographically flat nature. The use of remote sensing imagery provides a rapid and inexpensive means of acquiring preliminary information about the extent of flood hazard areas, information which can prove to be of use in regional and urban development.

This study involving the use of ERTS (Earth Resources Technology Satellite) and U-2 Infrared imagery has centered on the region north of Mobile Bay, Alabama and at the junction of the Black Warior-Tombigbee Rivers at a time of high discharge of river systems. Many of the principles involved, however, are applicable to flood hazard mapping in other areas and at times of low discharge.

The objectives of the study have been to determine which types of imagery allow the most accurate delineation of flood hazard areas, what the optimum scales are for mapping of the areas and what the costs involved are relative to conventional flood hazard mapping techniques.

The methodology involved in mapping the flood hazard areas is simple and requires only basic photographic items; a slide projector

data are due chiefly to the fact that the flood frequency at the time of the ERTS overflight was of 30-year recurrence, rather than 100-year--the basis for the U.S.G.S. ground truth data. There is agreement, however, for 97% of the flood hazard area.

At the junction of the Black Warrior and the Tombigbee Rivers, correlations between ERTS and U.S.G.S. data are poorer (83% agreement) and geomorphic features of flood plains have been used to aid in the hazard mapping. The region between the river's junction and the environs north of Mobile Bay is not covered by U.S.G.S. flood hazard maps. The "flood hazard" area in this region has been mapped from the ERTS data for some 400 miles of river (scale 1:250,000).

Figure 2 represents the correlation between tonal anomalies on the U-2 infrared imagery and U.S.G.S. ground truth data; the scale of this mapping was done at 1:62,500. In general areas of disagreement between the U-2 and U.S.G.S. data are similar to those seen for the ERTS data and the reasons for the disagreement are generally the same. It is felt that the U-2 imagery can be used accurately at a scale of 1:24,000, or smaller. Ground truth data for this area were not available at this scale, however, so the correlation has not been made.

The costs of using remotely sensed data for flood hazard mapping are significantly less than the more traditional methods. If the imagery is available, costs are on the order of a few cents per kilometer of river mile. As noted above, however, ERTS imagery cannot be effectively used at scales approaching that of the U-2 overflights.

The use of ERTS imagery is recommended for large scale flood mapping on, perhaps, a regional basis with imagery such as that acquired from U-2 overflights being used for urban studies. With sufficient experience, flood hazard areas may be delineated at times of non-flooding,

thus significantly expanding the potential use of this mapping method. At times of non-flooding geomorphic features characteristic of floodplains and flood-plain water tables close to the surface may allow use of infrared imagery for mapping purposes.

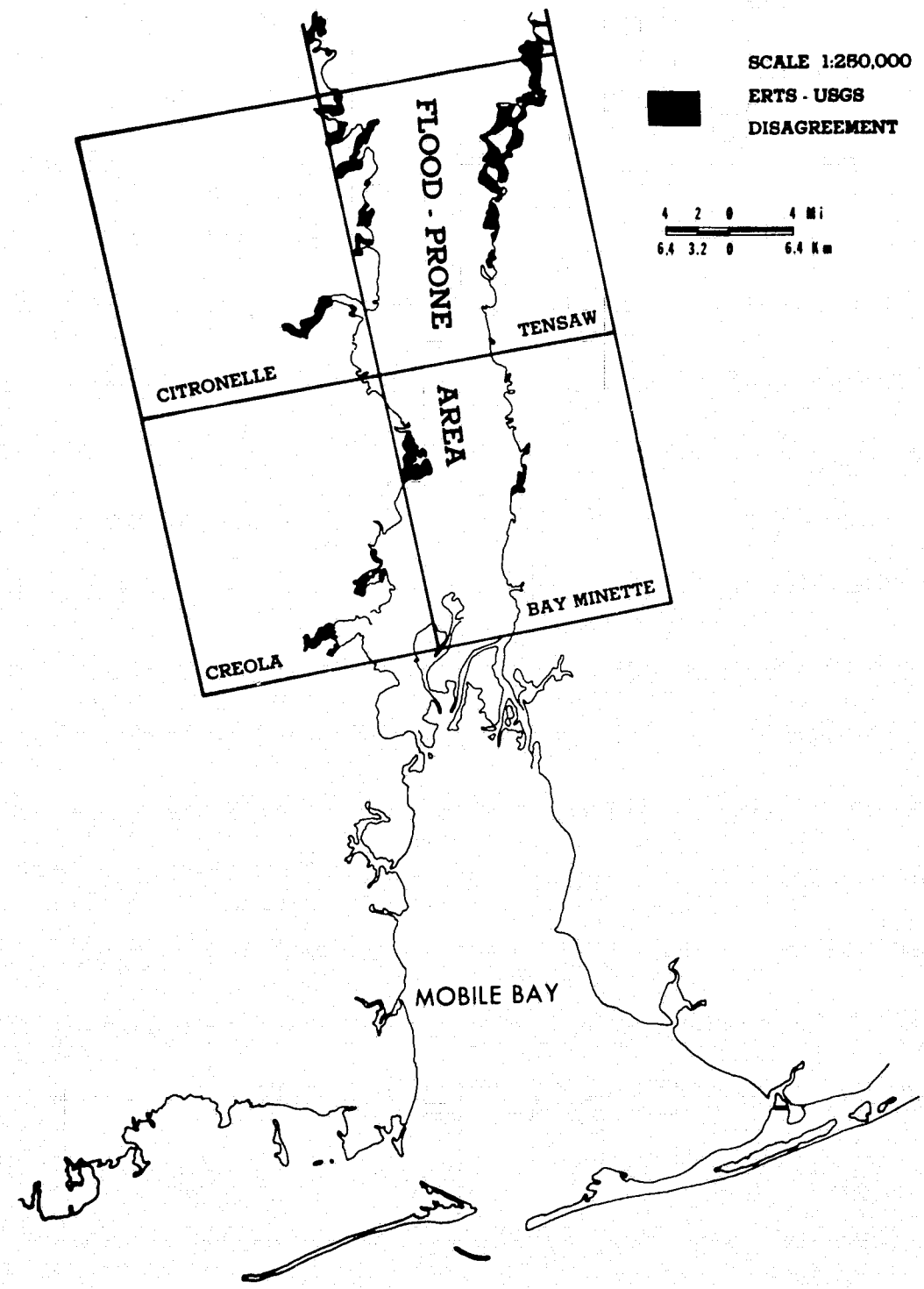


FIGURE 1

Correlation between USGS flood hazard data and ERTS (January 15, 1973 MSS band 7) flood hazard data for the southern scene. The original correlation was made at 1:250,000 scale.

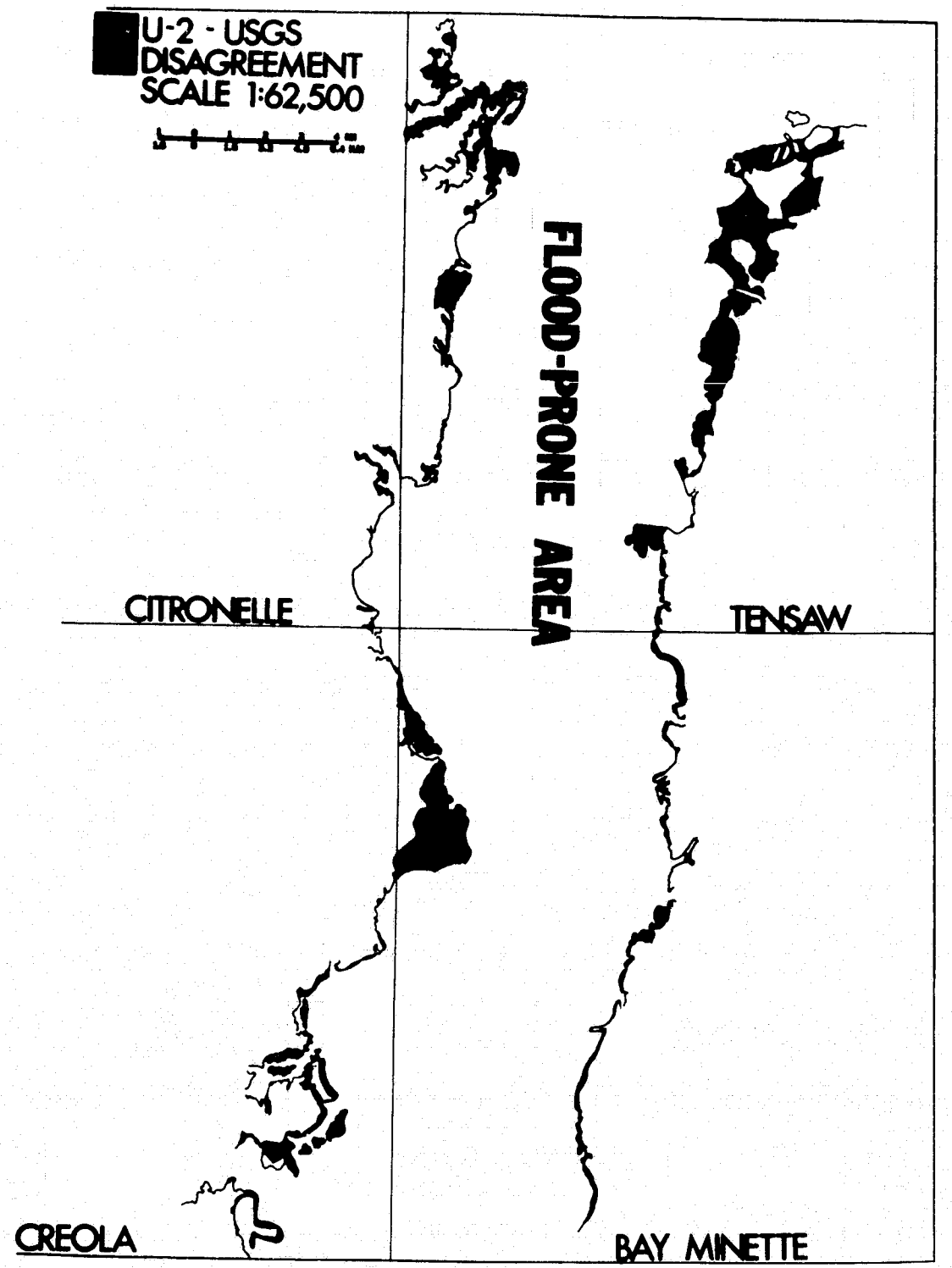


FIGURE 2

Correlation between USGS flood hazard data and U-2 flood hazard data for a portion of the southern scene. The original correlation was done at 1:62,500.

# PROGRAM DEVELOPMENT AND APPLICATIONS OF REMOTELY SENSED DATA BY THE GEOLOGICAL SURVEY OF ALABAMA*

by
C. Daniel Sapp
Chief, Remote-Sensing/Topography Division
Geological Survey of Alabama
P.O. Drawer O
University, AL 35486

## INTRODUCTION

### PURPOSE

The Geological Survey of Alabama has applied remote sensing to various problems in the earth sciences for several decades. This paper reviews the agency's recent expansion of manpower and physical facilities devoted to exploitation of remotely sensed data, and the services now rendered to the user community in Alabama. Current applied problems are reviewed in terms of acquisition and data analysis, and finally, current research topics are outlined.

### ORGANIZATION

The Remote-Sensing/Topography Division manages the Survey's remote-sensing programs and projects; stimulates research; and continually acquires, catalogs, stores, and manages remotely sensed data. This depository is the largest source of remotely sensed data at the state level in Alabama. Activities are user-oriented, but also include in-house service to the professional staff, as well as research within the division.

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*Approved for publication by the State Geologist

## IMAGERY ACQUISITION PROGRAM

The Survey uses its Cessna 206 aircraft for hand-held photography and low-level visual observation of the surface phenomena of Alabama. The organization was until recently engaged in a systematic program of imagery acquisition in cooperation with the U.S. Geological Survey, Prescott Research Group, from Prescott, Arizona. Various aerial platforms were used in combination with an array of sensors selected on the basis of project requirements, and the resultant imagery remains a valuable reference. In 1974, a Mohawk aircraft was used to gather side-looking airborne radar imagery of the Piedmont; a Beaver was used to obtain thermal imagery of many parts of the state, including all of the coastline; and a Cessna 180 was used to acquire color-infrared and black-and-white infrared photography of extensive parts of Alabama, including the oil fields. This cooperative program was very successful in meeting our acquisition needs.

The ERTS-1 (now Landsat) imagery has proved useful, but only as a supplement to our primary source of data, which is aerial photography. Skylab photography is useful, but is limited because of lack of repetitive coverage.

## EROS BROWSE FILE

The Geological Survey of Alabama is an established "browse file", and as such receives updates of Landsat imagery acquisitions from the EROS Applications Assistance Facility. Landsat, Skylab, and aerial imagery are received and maintained as 16-mm microfilm cassettes that are read on a Recordak viewer with digital interface. This viewer serves as a source of data on all

types of imagery and also as a data reference for new acquisitions. Other similar "browse files" in the Southeast are established at TVA Maps and Surveys Branch in Chattanooga, NASA Earth Resources Laboratory at Marshall Space Flight Center, and the Florida State Topographic Office in Tallahassee.

## APPLICATIONS

### OIL-FIELD SURVEILLANCE

Remote sensing at the Geological Survey of Alabama consists of a mixture of continuing programs and one-time research projects. One continuing program involves surveillance of oil-field activities in south Alabama for the State Oil and Gas Board. Routine overflights at low altitude are made with cameras using black-and-white infrared and color-infrared film. We are looking for contamination of surface and ground water by leakages from lines carrying brine, or by leakages of oil itself. In December 1974, we used a Texas Instruments thermal-infrared scanner at night to image thermal patterns in our largest oil field at Citronelle. We simulated a spill of salt brine from a tank battery and detected the hot fluid very easily. The purpose of this experiment was to determine our capabilities for detecting and monitoring brine and oil spills that may occur in the future. The photographic overflights were intended to monitor vegetative stress, oil-field activities, and other problems related to oil and gas exploration and production.

## MAPPING SURFACE MINES IN THE WARRIOR COAL FIELD

A recently completed project, funded by NASA/Marshall, involved use of remotely sensed data to map the present (1976) distribution of surface mines in a 300-square-mile (777-sq. km) area in Walker County. Aerial photography as old as 1938 was used to determine historical trends by mapping previous mining activity. An $I^2S$ color additive viewer was used with multiband aerial photography, and color infrared photography was flown by NASA in order to map existing patterns.

The objective of the project was to depict estimated original in-ground and remaining strippable coal resources, thickness of coal and overburden, and general chemical character of the coal. Tabular data were generated to provide details on strippable coal reserves.

Two additional surface-mine mapping projects are currently underway. The first, funded by NASA/Marshall, is a computer analysis of surface mines and coal resources in another 300-square-mile area astride the Jefferson County-Walker County border in Alabama. This study involves digitizing of drill-hole data and referencing by UTM grid, use of Army TOPOCOM topographic digital tapes, and supplemental use of Landsat CCTs (computer-compatible tapes). The Georgia Institute of Technology is assisting the State Survey in the computer analysis. Eventually, the techniques and programs should be extended to the remainder of the 3,000-square-mile (7,770-sq. km) Warrior Coal Field in Alabama.

The second ongoing study involves a cooperative effort with the Mississippi State University Forestry Department to map existing patterns and attributes of surface mines in the entire Warrior Coal Field, using Landsat CCTs. The automated analysis will be evaluated in terms of field data provided by the Geological Survey of Alabama, and the programs produced will be applicable to future updates of surface-mine patterns in Alabama.

## ALABAMA COASTAL MARSH INVENTORY

This project was completed in September 1976 and was funded jointly by the Federal Office of Coastal Zone Management and the Geological Survey of Alabama. The Alabama Development Office administered the one-year program through the Alabama Coastal Area Board.

Coastal saline and brackish marshes were mapped wherever they appeared in Alabama, including Perdido Bay, Wolf Bay, Mississippi Sound, Mobile Bay, and Dauphin Island. The mapping was heavily supported by field work because the existing aerial photographs were not adequate, being panchromatic and obtained during winter. This project involved mapping of vegetation at the species level. The maps are extremely detailed and are at scales of 1:12,000 and 1:24,000.

## ANALYSIS OF COASTAL AND BATHYMETRIC CHANGES IN THE COASTAL AREA

The Remote-Sensing/Topography Division conducted a systematic study of shoreline configurational changes in Alabama using aerial photography, Landsat imagery, and topographic maps, as well as nautical charts. Some rather drastic

changes were discovered, and it appears that these changes are related mostly to man's activities in the Mobile area. In lower Mobile Bay, islands have been reduced in size, some have disappeared, and one has prograded westward.

The division recently completed a comprehensive study of the entire bay to determine the changes in shoreline and bottom configuration, geology, and sedimentation characteristics that have occurred from 1900 to the present. This study was funded jointly by the Alabama Development Office Coastal Management Board and the Geological Survey of Alabama, and was published as Geological Survey of Alabama Information Series 50.

## TENNESSEE-TOMBIGBEE WATERWAY FLOOD MAPPING WITH AERIAL PHOTOGRAPHY

This ongoing, one-year project has as its objective the production of semicontrolled, rectified aerial photographic mosaics depicting the Alabama segment of the Tennessee-Tombigbee Water at 1:12,000-scale. An annotation of the 1973 flood limits is being shown on the 1973 photographs, along with other hydrologic data. This project is being funded by the Army Corps of Engineers, Mobile District.

## LINEAMENTS

A subject of continuing research at the Survey is lineaments. Investigators first became aware of a series of tonal alignments through analysis of Apollo 9 multispectral photographs of east-central Alabama in 1969. Two major lineaments were exceptionally well displayed on Apollo photography and later, through the use of ERTS imagery, were extended into areas of the state where satellite imagery

was previously unavailable. The two lineaments appear to have regional geologic significance.

The lineament orientations and pattern density show a relationship to the location of high-yield springs and wells. They probably reflect fractures that control the distribution of ground water in the area. A correlation is also indicated between the lineaments and known hydrothermal mineral deposits of the Valley and Ridge and Piedmont in Alabama. Seismicity, in addition, appears to be related to the lineaments, as 6 out of 14 earthquake epicenters reported for Alabama coincide with the major lineaments. The coincidence suggests the possibility that the lineaments are related to major basement structures that are still active.

## TOPOGRAPHIC MAPPING PROGRAM

The Remote-Sensing/Topography Division has a manifold interest in topographic mapping. First, it has a Kelsh plotter with Stereo Image Alternator, which is used occasionally to support geologic and environmental projects. For example, a number of proposed industrial sites were recently mapped at large scale with a 5-foot contour interval, using aerial photographs obtained on contract. Second, it maintains a file on geodetic control , primarily for in-house use but also available to the public. The third area of interest in topographic mapping involves liaison with the U.S. Geological Survey, Topographic Division, in Reston, Virginia. The State Survey serves as coordinator for Alabama's topographic mapping program and, through it, provides matching funds for the work. Approximately 90 percent of Alabama's area is covered by $7\frac{1}{2}$' Series maps. Much of this $7\frac{1}{2}$' Series mapping was done and is maintained by TVA.

## PHYSIOGRAPHIC MAPPING

The Remote-Sensing/Topography Division recently produced a revised physiographic map of Alabama, which was printed at 1:1,000,000 scale and published as Special Map 168. The map shows physiographic regions, including 5 provinces, 5 sections, 28 districts, and 3 subdistricts. The traditional classification system was revised at the district and subdistrict level, to produce an improved physiographic map of the state from the best available sources. Also, in the course of this project, the value of Landsat imagery for the task was evaluated.

## LANDSAT COLOR MOSAIC

A color mosaic of Alabama was constructed for the Geological Survey of Alabama by the EROS Applications Assistance Facility at the National Space Technology Laboratories in Bay St. Louis, Mississippi.

## SUMMARY

Remote-sensing technology has been and continues to be of practical use to members of the Survey staff. This includes those people involved in geologic and geographic research as well as those in hydrology and energy resources. Remote sensing not only allows the Survey to carry out its duties more efficiently, but in some instances is indispensable for providing data that cannot be obtained by other methods.

# USE OF REMOTE SENSING IMAGERY FOR ESTIMATION OF EROSION AND SEDIMENTATION RATES IN STRIP MINED AREAS

Travis H. Hughes
Department of Geology and Geography
University of Alabama
University, Alabama 35486

Under a series of contracts with NASA-Marshall Space Flight Center, the Department of Geology and Geography has performed research related to erosion and sedimentation in strip mined areas. The goal of this research is to develop techniques for estimating the volume of material eroded and the resultant sediment volume by use of aerial photography or other remotely sensed imagery.

## EROSION IN STRIP MINE SPOILS

In order to provide reliable estimates of erosion, we have concentrated research efforts toward measurement of material removed from rills and gullies occurring on the steep slopes of unvegetated spoils from strip mining. The age range of the spoils is 0-20 years. The slope angles vary from $32^{o}$ to $38^{o}$ with a mode of $36^{o}$. Estimates of erosion must be modified for slope angles other than those above.

In the early stages of slope development, sheet wash may produce 50 percent of the total erosion (estimates by various authors show a range of 40-60%) from unrilled portions of the slope. Sheet wash from the divide areas, separating individual rills and gullies, has not been measured in our studies.

The volume of rill and gulley erosion has been measured for 20 steep slopes ($36^{o}$), of known age (0-19 yesrs) in an area near Searles,

Tuscaloosa Co. AL. Linear regression analyses of the data indicate the following relationships between volume of material removed (per unit area of slope) and age:

(1) $V\ (m^3/\text{hectare}) = 802(1.1^t)$

where

V = volume of material removed from rills and gullies, expressed in cubic meters per hectare of slope area.

t = time, in years, since creation of the slope.

If the data are represented in cubic yards per acre of slope, then equation (1) becomes:

(1a) $V\ (yd.^3/\text{acre}) = 424.5\ (1.1^t)$

Graphic illustration of equation (1) is shown in Figure 1.

Our method of applying equation (1) is as follows:

1. Measure (planimeter) the area of steeply sloping spoils in the area of interest.
2. Convert the measured area (map area) to true slope area (divide by cos $36^o$).
3. Use the known age of mining and equation (1), (1a), or Figure 1 to determine the volume of erosion per unit area of slope.
4. Multiply true slope area (step 2) by the volume derived in step 3. This will provide an estimate of the amount of rill and gulley erosion on steep slopes.
5. Repeat steps 1 through 4 for gently sloping areas within the strip mines. Gentle slopes in the Searles area average about $15^o$, thus we use cos $15^o$ to calculate true slope area (step 2).
6. The results from step 5 must be modified since gentle slopes undergo less erosion than steep slopes. Use the graph in

FIGURE 1
VOLUME OF MATERIAL REMOVED VS. TIME

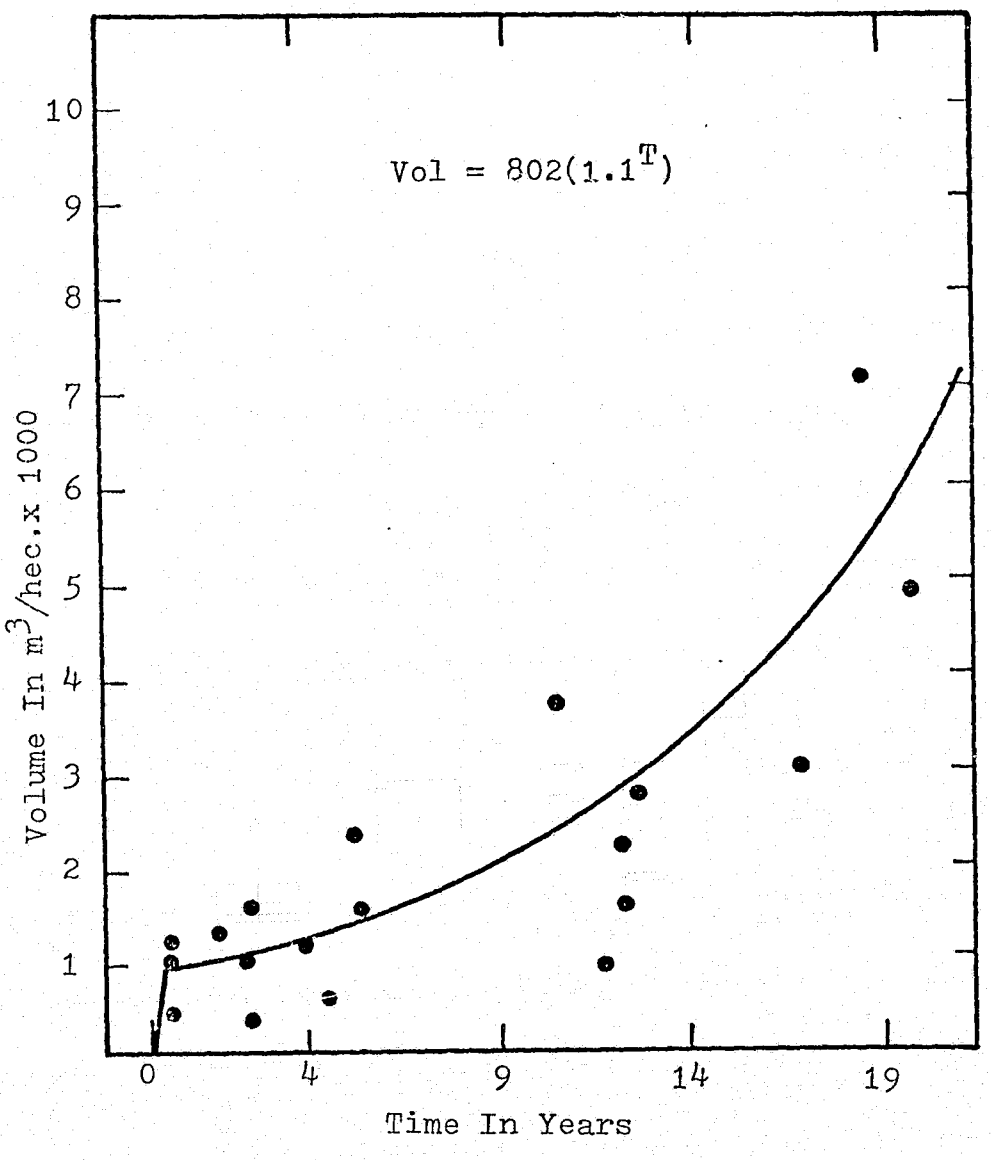


Figure 2 to determine the percentage decrease in erosion on gentle slopes. For example, Figure 2 indicates 22 mm of erosion on 36° slopes and 8 mm of erosion on 15° slopes. Division of 8 x 22 yields 0.36. Therefore, multiply the results from step 5 by 0.36.

7. Add the volume of rill and gulley erosion from steep slopes to the volume calculated for gentle slopes to get total rill and gulley erosion.

In the Searles mining area steep slopes occupy 30 percent of the total mined area, gentle slopes occupy 41 percent, and the remaining 29 percent of the mined area includes flat areas of valley bottoms and tops of spoils. Since 15° slopes produce 36 percent of the erosion produced from 36° slopes, the total erosion can be calculated by measuring the total mined area and multiplying by 0.446, which is equal to 0.30 + 0.41 X 0.36.

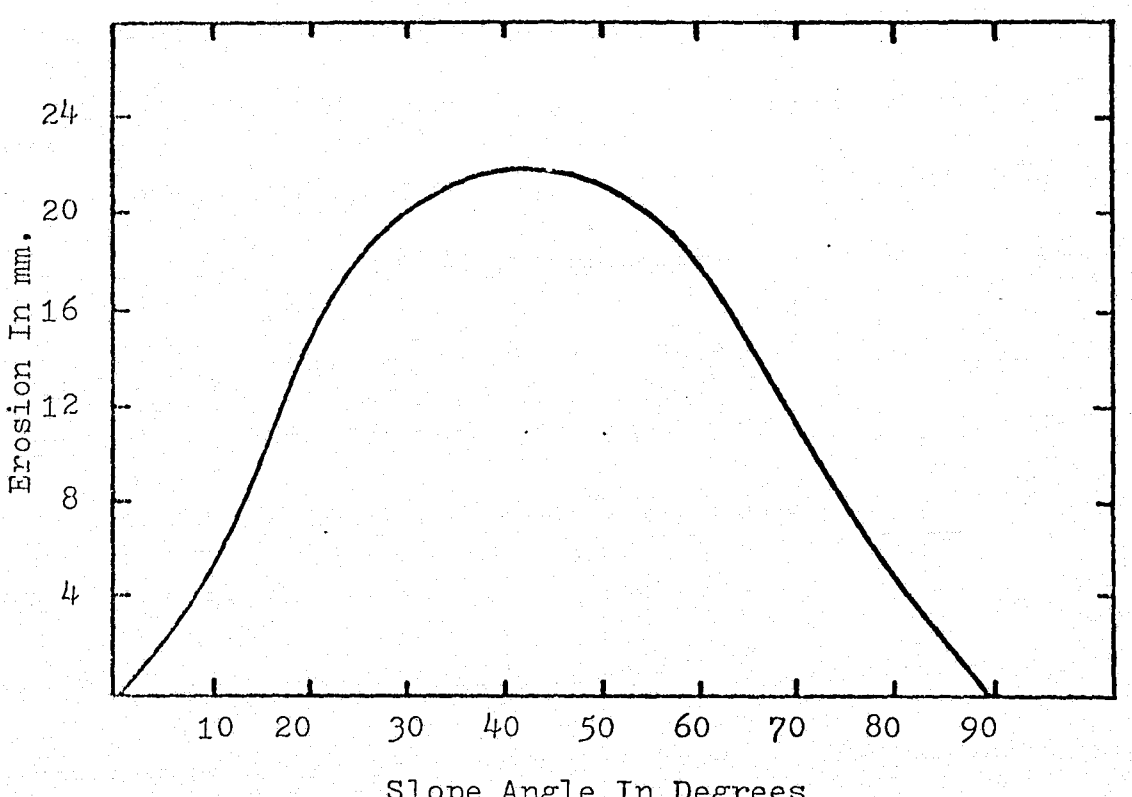
Our estimates ignore sheet wash from the divides between individual rills and gullies and assume no erosion in the flat areas of the strip mines. Sheet wash may produce 50 percent of the total erosion from mined areas in the first few years after mining. Sheet wash and stream erosion remove material from the flat areas. Therefore, the total erosion in strip mined areas may be double the calculated amount.

## SEDIMENTATION AS A RESULT OF STRIP MINING

Lake Harris was created in 1929 as a municipal water supply reservoir for the City of Tuscaloosa. The original storage capacity of the lake was 2,986,259 cubic meters (2,421 acre-feet) at crest elevation of 61.57 meters (202 feet). Strip mining for coal during

FIGURE 2

EROSION VS. SLOPE ANGLE



the years 1966 to 1969 disrupted 32.7 hectares (80.9 acres) of land in the drainage basins of three tributaries which drain into Lake Harris. Two deltas have been formed in Lake Harris as a result of accelerated erosion in the strip mined area. The northern delta occurs where tributaries B and C enter the lake (see Figure 3) and the southern delta occurs at the mouth of tributary A. Neither was visible on aerial photographs taken before 1967.

As an attempt to measure the growth of each delta we used U. S. Soil Conservation Service photographs taken in 1967 and 1972, U. S. Geological Survey photographs (1974), NASA U-2 photographs (1973), and NASA Skylab photographs (1973). The delta outlines were transferred from the photographs by means of a camera lucida attached to a microscope at 25x magnification. The surface areas of the deltas were measured with a polar planimeter. The area of each delta, the slope of the delta surfaces, and the slope of the foreset beds of each delta was determined by plane-table mapping during the summer of 1976. Pre-delta cross-sections of each valley were constructed, on 100-foot spacing, from topographic maps published in 1928.

The information taken from the photographs, the area of the valley cross-sections, and projection of slopes on the delta surfaces allowed calculation of the volume of the deltas for the years 1967, 1972, 1974, and 1976. The results of our calculations are shown in Table 1. Linear regression analyses of Log length vs. age, log area vs age, log volume vs. log length, and log volume vs area allows estimation of the size and volume of the deltas at any time. The results are shown in Figures 4, 5, 6, and 7. At present rates of sedimentation one year's sediment accumulation in the southern delta is

FIGURE 3

DRAINAGE BASINS AND STRIP MINED AREA

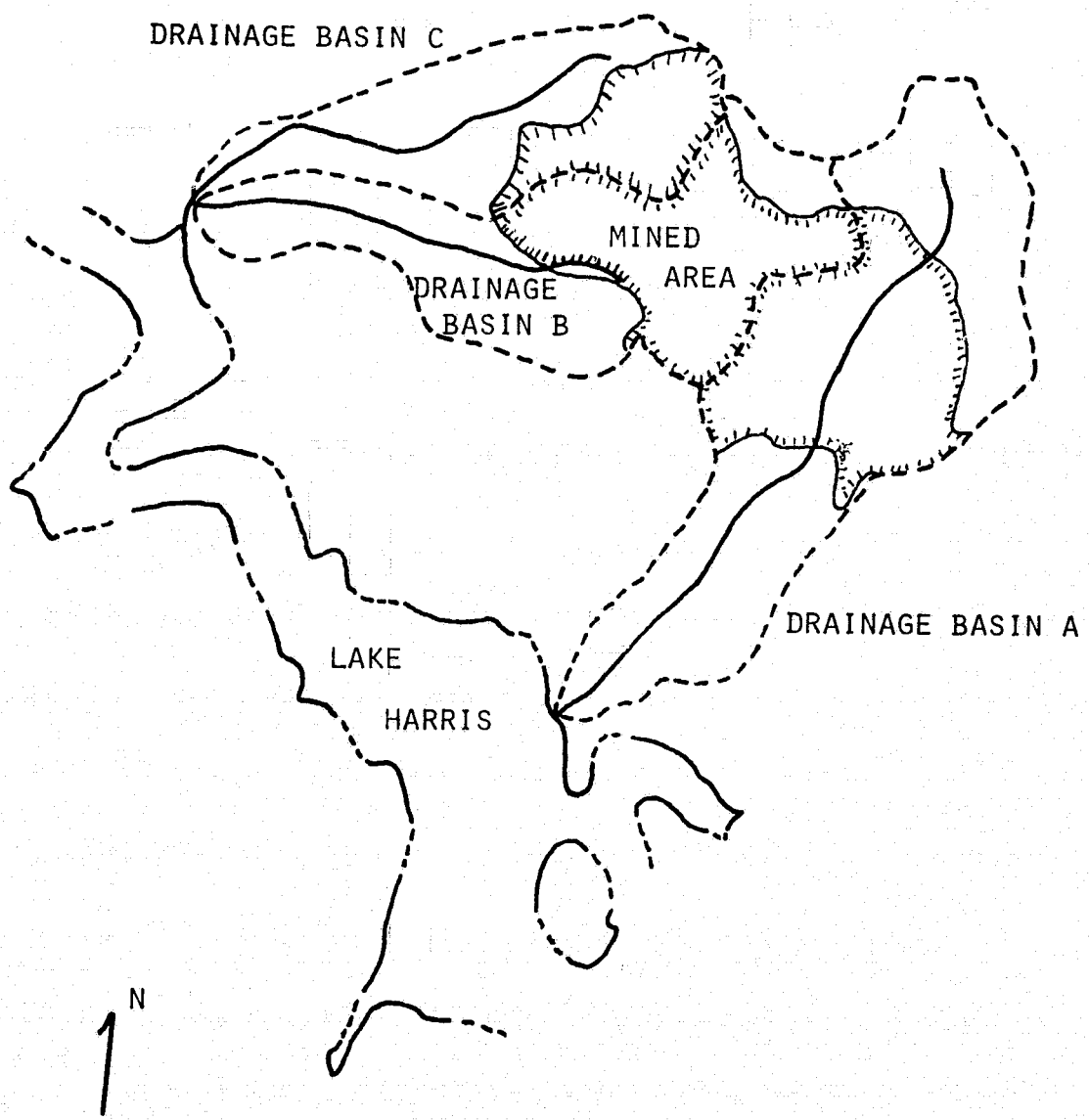


TABLE I

SOUTH DELTA

| YEAR | DATE | LENGTH M | SURFACE AREA $M^2$ | VOLUME $M^3$ |
|---|---|---|---|---|
| 0 | 1966 | | | |
| 1 | 1967 | 91 | 2,300 | 11,000 |
| 6 | 1972 | 104 | 3,500 | 30,000 |
| 8 | 1974 | 122 | 3,600 | 35,000 |
| 10 | 1976 | 140 | 5,000 | 57,000 |

NORTH DELTA

| YEAR | DATE | LENGTH M | SURFACE AREA $M^2$ | VOLUME $M^3$ |
|---|---|---|---|---|
| 0 | 1966 | | | |
| 1 | 1967 | 203 | 11,110 | 60,000 |
| 6 | 1972 | 223 | 11,700 | 84,000 |
| 8 | 1974 | 274 | 15,400 | 129,000 |
| 10 | 1976 | 323 | 16,000 | 180,000 |

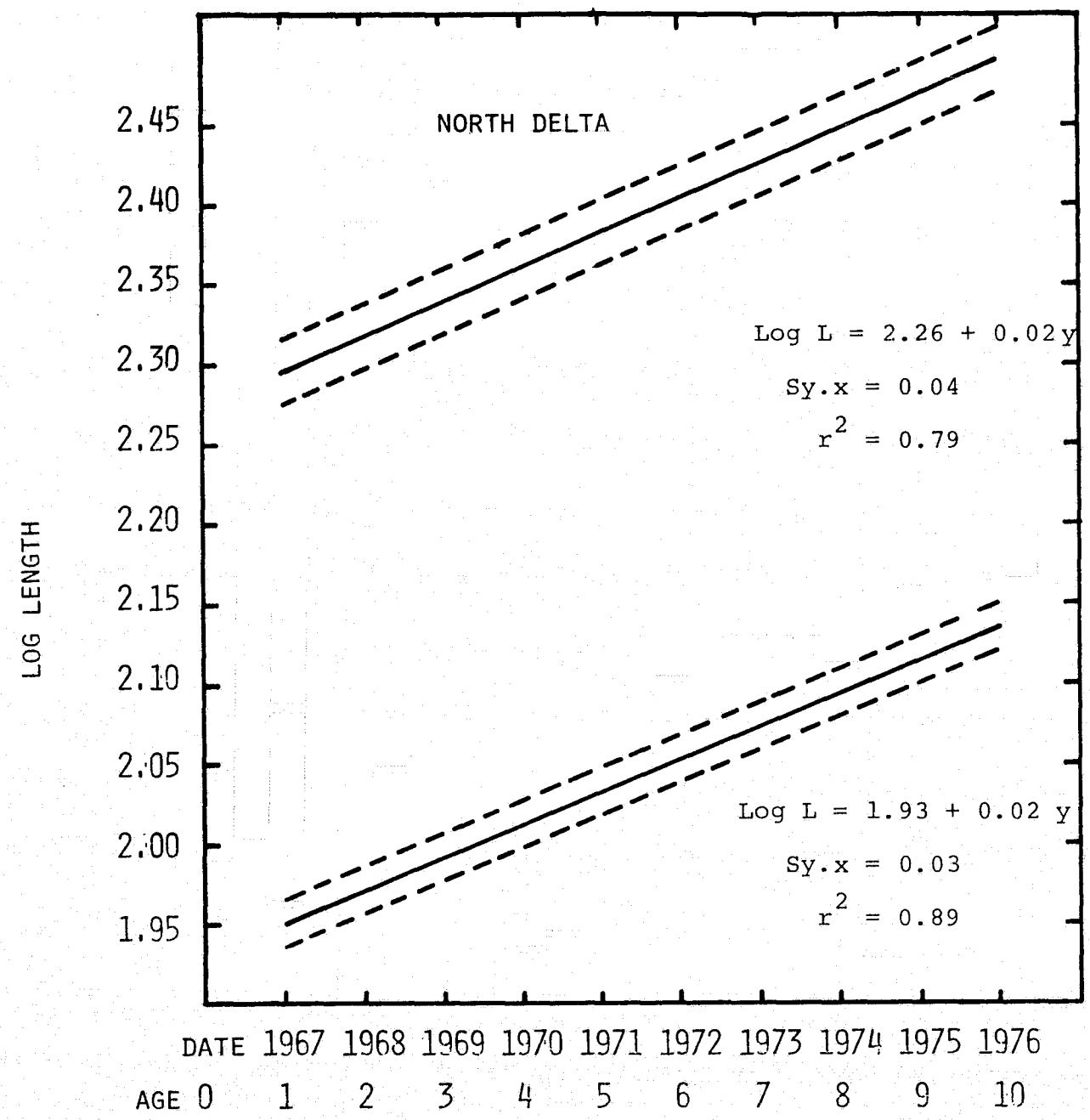



FIGURE 4

LOG LENGTH VS. AGE

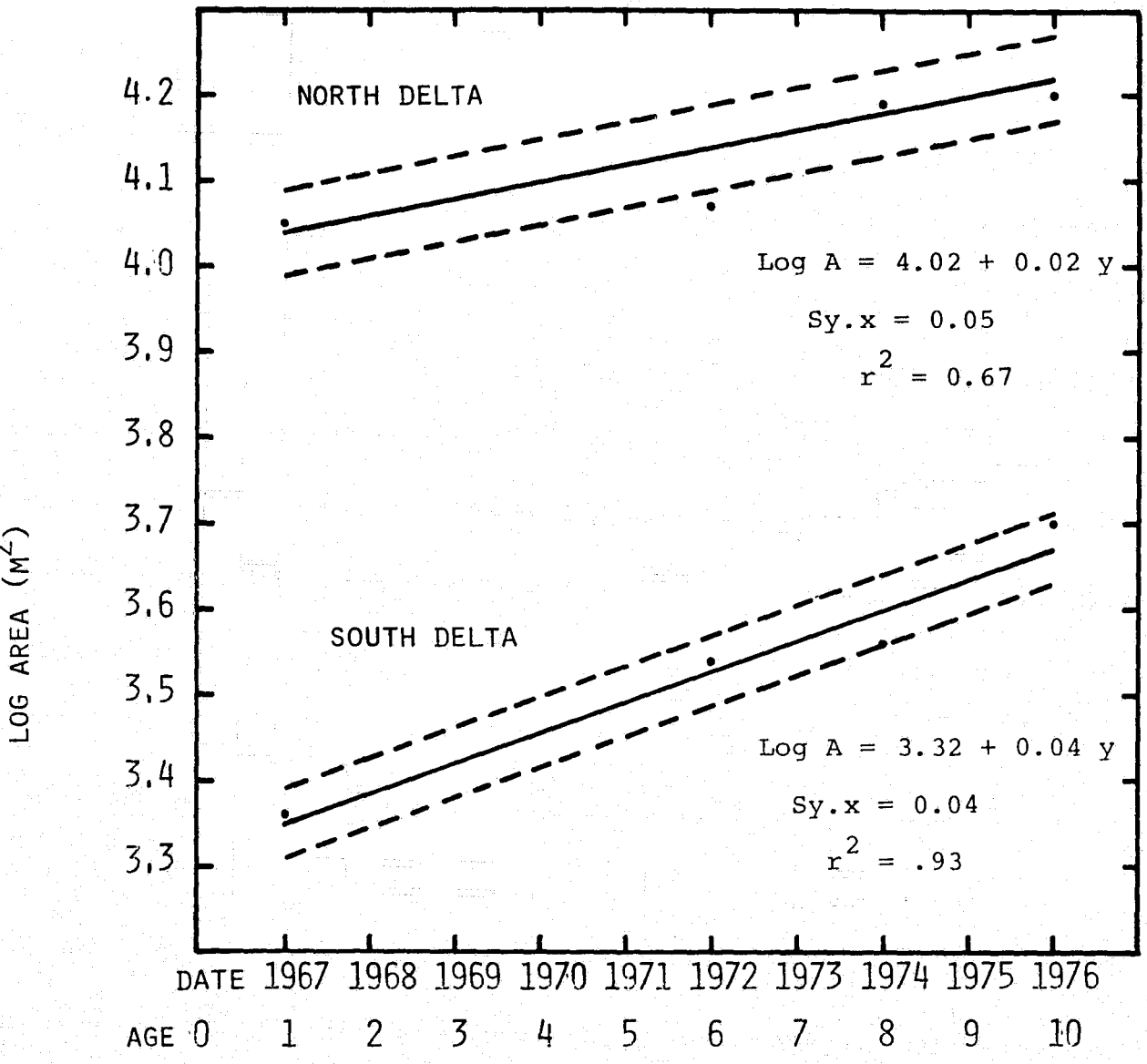



FIGURE 5

LOG AREA ($M^2$) VS. AGE

FIGURE 6

LOG VOLUME VS. LOG LENGTH

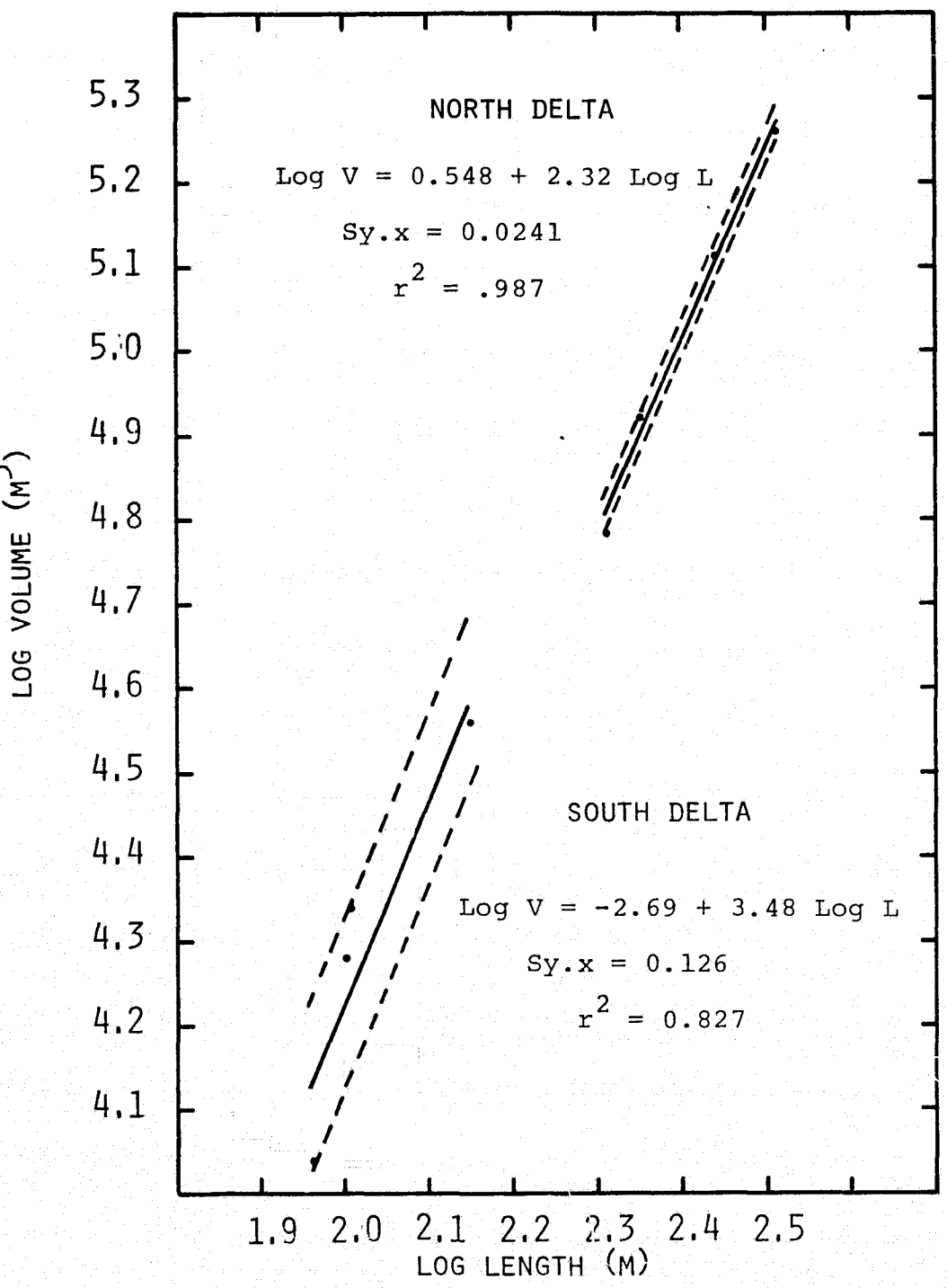
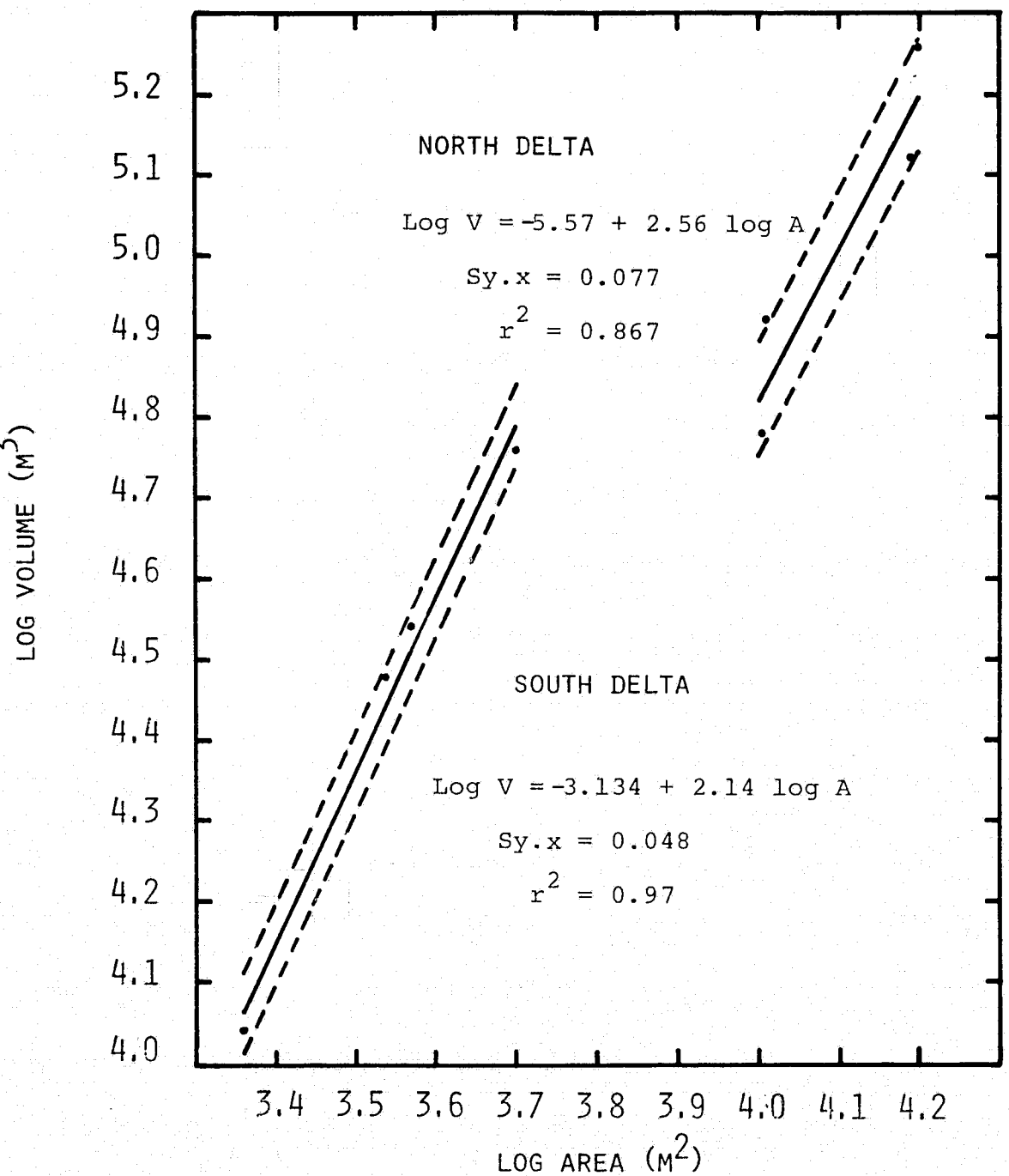


FIGURE 7

LOG V. VS. LOG A

VOLUME ($M^3$) AREA ($M^2$)



equivalent to 146 year's accumulation of sediment under natural conditions. In the north delta sediment accumulation has been enhanced by a factor of 364.

# LITHOLOGIC DIFFERENTIATION BY USE OF REMOTE SENSING IN A VEGETATED REGION

Rex C. Price and S. H. Stow, Leaders

Lithologic mapping is an integral part of proper land use since certain rock types (clay, sand, etc.) are suitable for specific uses. Lithologic mapping must involve field work, but may be significantly aided by use of aerial photographs. Numerous studies have been conducted concerning lithologic mapping from aerial photographs in sparsely vegetated regions. Studies in vegetated regions have been restricted to broad regional lithologic or soils mapping. This study involves developing a technique for lithologic differentiation by aerial photo interpretation in a vegetative region.

Different types of vegetation emit characteristic spectral responses which are detected by remote sensors. Local vegetative zonation is primarily controlled by underlying lithologies (Harper, 1913). Certain vegetative types can result in spectral signatures characteristic of specific lithologies.

In order to obtain lithologic information, it is not mandatory to have highly sophisticated equipment. Subjective analyses can be conducted by using multispectral positive prints or transparencies mounted on a light table. Although this study involved non-automated visual interpretation it remained objective by explaining causal relationships between tonal and textural qualities of the photo and terrain parameters (ground truth).

The four multispectral bands analyzed are as follows: band 1 (blue), band 2 (green), band 3 (red), and band 4 (infrared). Tonal and textural properties of photographs were analyzed with the realization that they represent secondary and tertiary evidence regarding underlying lithologies. Spectral responses of different surficial materials were compared with tonal and textural qualities of the photo. Photograph tone and texture are principally controlled by drainage characteristics (erosion, gulleying, and drainage patterns), landforms (topographic expression, slope angle, and microclimatic differences), and vegetative cover. Relationships between these above mentioned factors and specific lithologies were also determined, however, before inference was made comparing tonal and textural qualities of photographs to specific lithologies. The surface characteristics of the land are an intermediate stage between the end member of photograph tone and texture and the end member of lithologic differentation.

Any photo interpreter attempting to differentiate lithologies in a humid region must be aware of several potential problems concerning reflectance surfaces. Recognition of these problems must be a subjective part of any analysis and therefore necessitates visual interpretation. Problems encountered are: 1) difficulty in field differentiation of lithologic contacts due to weathering and due to rapid lateral and vertical facies changes, 2) reflectance intensities controlled directly and indirectly by topography, 3) variables affecting natural vegetal zonation and, 4) man-made vegetal land-use patterns. Problems complicating photo interpretation, other than those previously mentioned concerning the reflectance surface, are often inherent with the imagery. Inherent problems include shadows

due to sun angle, prevailing weather conditions at time of flight, season of flight, and also parallax due to increased viewing angle along scene margins.

Tonal differences of surficial material and features as viewed on multispectral imagery are as follows:

VISIBLE LIGHT (Blue, Green and Red Bands)

Bare Areas - Good reflectance, therefore roads and bare fields show up as the lightest areas on the photographs.

Broad Leaf Vegetation - Low reflectance due to large amounts of absorption by chlorophylls (dark tone). Generally associated with high moisture content (clay rich).

Planted Pines - Pines exhibit less reflectance than broad leaf vegetation. Very dense, masking ground reflectance, planted pines are generally darker than broad leaf vegetation but are not readily differentiated.

Natural Pines - Generally are controlled by sandy lithology and are found associated with black jack or scrub oaks. Because of the low density of natural pines (increasing the ground reflectance), this area appears as an intermediate gray tone. Natural pine stands are lighter toned than broad leaf vegetation and are easily differentiated.

Water - medium gray (not very distinctive).

Topography - Topography is not readily differentiated because topographic reflectances, when combined with lithologic reflectances, result in an intermediate gray tone.

NEAR INFRARED

Bare Areas - Medium gray tone and fine textured. The tone, subject to change with varying amounts of rainfall, darkens with increased moisture content.

Broad Leaf Vegetation - High reflectance (light color) mainly due to the internal structure of the individual leaves within the leaf canopy.

Planted and Natural Pines - Pines are poor reflectors and are therefore dark toned. Planted and natural pines cannot be easily differentiated because the barren areas associated with natural pines are not as reflective in infrared as was the case in visible light.

Water - Dark toned due to absorption and little reflectance.

Topography - Topographic and lithologic reflectances accentuate each other on the infrared band causing hills to appear dark while valleys are light toned.

Note that by using a combination of visible and infrared photographs, natural pines, planted pines, and deciduous vegetation can be easily differentiated.

Tonal and textural overlays were constructed and percent correlation with lithologies was determined. Quantitative tonal values of specific locations on the image were objectively compared with moisture and grain size analysis. Best correlation for lithologic differentiation was for the red and infrared multispectral bands. Since vegetative types are variable, quantitative comparisons between vegetation and tonal values of imagery was not attempted. However, subjective comparisons were made. After tonal values were analyzed in relation to ground truth, signatures were developed for differentiating sand, clay, alluvium, terrace deposits, and indurated sedimentary rocks. Signatures are more readily identified on the infrared band and are as follows:

Sand - Sand hills are generally dark toned. Closer analysis with a stereoscope indicated tonal separation due to slope exposure. North facing slopes appear lighter than do south facing slopes. The tonal differences are gradational and might be overlooked if careful analysis with a stereoscope is not conducted. Sandy slopes also appear dark but are homogeneously textured. This homogeneous photograph texture is probably due to the smooth regular terrain. Gullies or valleys which do form are generally V-shaped and have steep sides.

Clay - Clay hills vary from a homogeneous light tone to a darker mottled appearance. Mottled clay hills are topographically higher than are light toned clay hills. The mottled appearance could be controlled by high reflectance of vegetative types and low reflectance due to topographic position and slope angle. Moisture variance due to high topographic position could also cause tonal differences. Topographically high clay hills could be confused with sand hills. Clay hills, however, are coarse textured, mottled, and do not exhibit tonal variance due to north-south slope exposure. This coarse texture could be controlled by a more extensively developed drainage system which would have a variety of slope angles resulting in difference reflectance intensities. Vallies or gulleys would have gently sloping sides with broad flat bases.

Lower clay hills, coarse textured and light toned, are spectrally similar to alluvial deposits but are easily differentiated by their topographic position. Clay slopes and lowlands are finer textured, due to the level terrain, and are also light toned.

Alluvium - Areas of alluvial deposition generally appear light toned, coarse textured and mottled in appearance. The predominant light tone is due to the abundance of lush vegetation that borders streams or creeks. This light area would correspond to the sandy natural levee or flood plain. This light tone is in contrast to most sandy areas which are generally dark toned on the infrared band. Other light signatures on the image might be confused with alluvial deposits if it were not for the topographic position and characteristic coarse grained and mottled appearance.

Terrace Deposits - Terrace deposits vary depending on the underlying lithology. Regardless of the tonal response, terrace deposits should appear homogeneously textured. This textural characteristic would be controlled by the flat terrace surface reflecting light evenly to the sensor. Terrace deposits would best be delineated by the broad flat areal distribution and the proximity to adjacent streams.

Indurated Sandstone - Sandstone appears coarse textured and light and dark mottled in appearance. Predominantly dark, sandstone hills resemble unconsolidated sand hills. Sand hills, however, lack the mottled appearance and the coarse texture of sandstone hills. Sandstone hills can be differentiated from mottled clay hills by the varied topography and steep valley walls. The dissected topography of the sandstone hills causes the coarse mottled texture.

Characteristic signatures can be used to delineate broad lithologic types in a vegetated region. Due to the numerous variables that must be considered during analysis, intermediate lithologies

cannot be readily identified. Slight man-made disturbances of the reflectance surface could cause misinterpretations.

Multispectral analysis for lithologic determinations will prove beneficial if limited time is a factor and if areas to be mapped have limited accessibility. Photo analyses should, however, always be combined with field work.

# MEASUREMENT AND CALCULATIONS BASED ON DATA FROM REMOTE SENSING IMAGES

Travis H. Hughes
Department of Geology and Geography
University of Alabama
University, Alabama 35486

Calculations based on measurements from aerial photographs may be subject to serious errors unless the scale of the photograph is accurately known. In addition, application of appropriate correction factors for scale variation due to elevation differences, slope angle and facing direction, distance from center of photograph (principal point), and camera tilt may be necessary. Most aerial photographs used for measurement purposes are low altitude, vertical photographs. As a result, corrections for camera tilt and scale variation due to distance from the principal point are often negligable. Therefore, unless the worker is dealing specifically with measurements on slopes, the primary concern is to accurately calculate scale at a convenient elevation and determine if scale variation due to elevation differences is significant.

## Scale Determination

Presented in the following discussion are three methods of scale determination. Doubtless, other methods exist, understanding these three, however, will enable the worker to calculate scale, with reasonable accuracy, under almost any conditions he or she should encounter.

## Use of Ground Measurements in Scale Determination

Perhaps the easiest and most accurate scale determination results from measurement of the distance between two points, of

approximately equal elevation, on the ground and then measuring the distance between these same two points on the photograph. Both measurements should be expressed in the same units (i.e. centimeters, inches, or any other convenient units). The scale is simply the measured distance on the photograph over the measured distance on the ground (expressed as a fraction). For example, suppose the distance between two points of equal elevation on the ground is 305 meters (1000 feet) and the distance between these same two points, as measured on the photograph, is 3.05 centimeters (1.2 inches). Since there are 100 centimeters in one meter, the scale is

$$\frac{3.05 \text{ cm}}{30{,}500 \text{ cm}}$$

Because 30,500 divided by 3.05 equals 10,000 and because the units (cm) cancel, the scale is a unitless fraction expressed as 1/10,000, and indicates that one centimeter on the photograph is equal to 10,000 centimeters on the ground. Incidently, the scale would have been exactly the same had we used 1,000 feet (12,000 inches) and 1.2 inches in our calculations. Scale, as calculated above, means that one unit on the photograph is equivalent to 10,000 similar units on the ground surface, regardless of what the measuring units are (centimeters, inches, meters, pencil lengths, etc.).

## Use of Topographic Maps in Scale Determination

When measurement of the distance between two points is inconvenient or the area is inaccessible, scale can be determined by measuring the distance between two points, of approximately equal elevation, on a topographic map (of known scale) and measuring the distance between the same two points on the aerial photograph. Since the scale of the topographic map is known, the actual distance, between the two points

on the earth's surface, can be calculated and the problem becomes identical with the above scale calculation. Assume that the topographic map you are using is a standard 7½ minute quadrangle, which has a scale of 1/24,000. Further, assume the measured distance between two points, of approximately equal elevation, on the map is 15 centimeters and that the distance between these same two points on the photograph is 36 centimeters. Since the scale of the map means that one centimeter on the map is equal to 24,000 centimeters on the ground, then the actual ground distance between the two points is (15 x 24,000) or 360,000 centimeters. Because the distance between these two points on the photograph is 36 centimeters, the scale is 36/360,000 or 1/10,000.

Use of Aircraft Altitude and Lens Focal Length in Scale Determination

The third method of scale calculation is an accurate expression of the fact that distant objects look smaller than objects close to the camera.

Light passing through a camera lens can be focused to a point at a fixed distance behind the optical center of that lens. This distance is known as the focal length of the lens. A simple relationship between altitude of the aircraft and focal length of the camera is expressed as follows:

$$\frac{\text{Focal length of camera lens}}{\text{Altitude of aircraft above ground}} = \text{scale of photograph}$$

The most frequently used aerial photographic lenses for low altitude photography have a focal length of 15.24 centimeters (6 inches). These lenses are the standard for most photographs taken by The Soil Conservation Service, The U.S. Geological Survey, low altitude NASA photographs, and most private companies that provide aerial photographs.

An additional advantage to the user is that often the aircraft altitude is shown on the photograph.

Suppose, for example, the photograph with which you are working was taken at an altitude of 3048 meters (10,000 feet or 304,800 centimeters) with a camera which had a 15.24 centimeter (6 inch) lens. The photograph scale is then 15.24/304,800 or 1/20,000.

An interesting aspect of this last problem becomes apparent when you realize that the bottoms of valleys are farther away from the camera than are the tops of hills. It then becomes obvious that the scale of an aerial photograph differs depending on the elevation of the land surface. Did you wonder why you were asked to choose points of approximately equal elevation in the preceeding problems of scale determination?

Scale Variation due to Elevation of the Land Surface

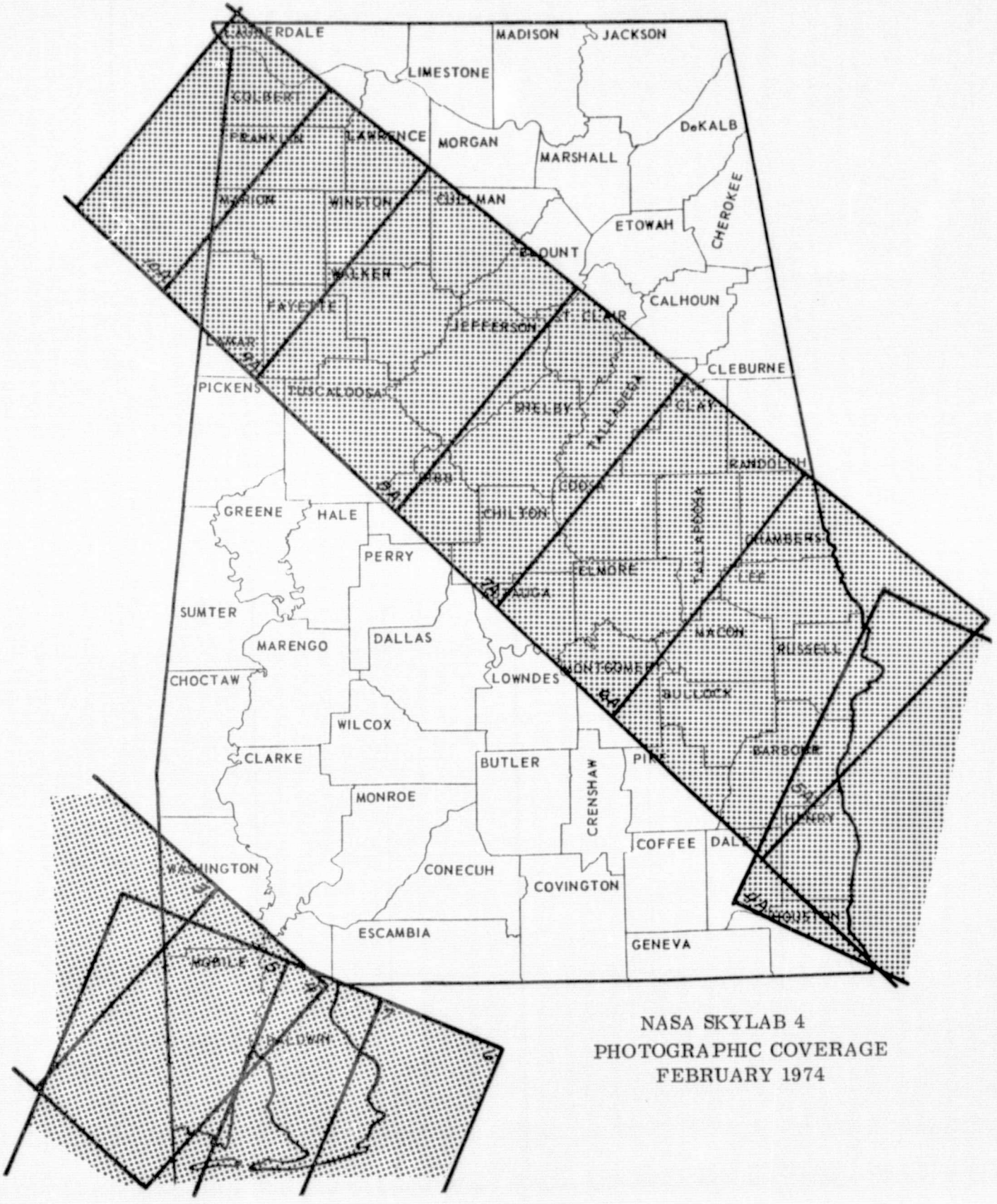
Whether scale variation due to elevation differences of the land surface is important for consideration depends on the required accuracy of measurement and the relief of the land (relief is defined as the difference in elevation of the lowest spot on the land surface and the highest point on that surface). If the land surface is flat or has a low relief, scale corrections due to elevation differences are negligible. If, however, the topography is mountainous or contains areas of greatly different elevations then serious measurement errors may be induced because of the elevation differences. Perhaps the easiest way to determine if significant scale changes occur due to elevation differences is to calculate the scale of the photograph from two points choosen near the highest elevations on the land surface and then recalculate the scale using points at the lower elevations.

In a recent project involving a drainage basin near Birmingham, the lowest elevation in the project area was 260 feet above mean sea level (MSL) and the highest elevation was 544 feet above MSL. (We will use feet as units in this example since the information occurs in these units on topographic maps.) The relief in the basin is, therefore, 284 feet. The scale of the photographs (calculated from points chosen on the topographic map) at the highest elevation is 1/11,586, and the scale calculated at the lower elevations is 1/12,154. This indicates that the maximum error of measurement due to elevation differences is 4.9 percent. In order to minimize errors of measurement we calculated the photograph scale at the median elevation of the basin. (The median elevation, 402 feet above MSL, is the elevation one-half way between the highest and lowest elevations.) Scale at the median elevation is 1/11,870. Using this scale in our calculations induced a maximum error, due to elevation differences, of only 2.3 percent.

One of the most frequently encountered problems when using aerial photographs is that vertical objects (trees, buildings, etc.) appear to be tilted outward, away from the center of the photograph and inclined areas (slopes) are elongated if they face toward the photograph center and are foreshortened if they face away from the center of the photograph. We have developed equations for derivation of slope correction factors which incorporate facing direction of the slope, angle of camera view, slope angle, and distance from the principal point of the photograph.

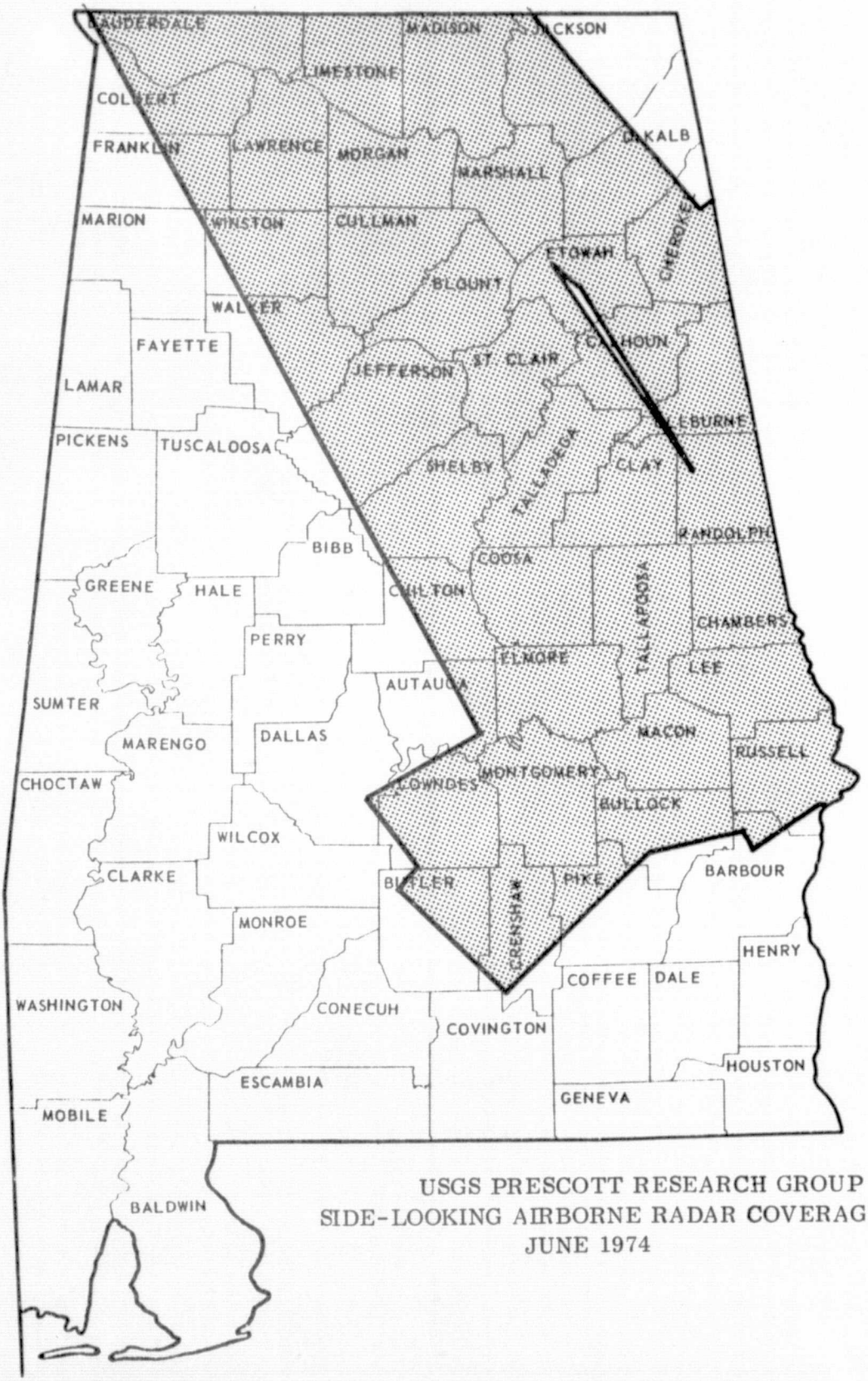
# APPENDIX A

Areas covered by various types of imagery. Available for user dissemination by the Geological Survey of Alabama.

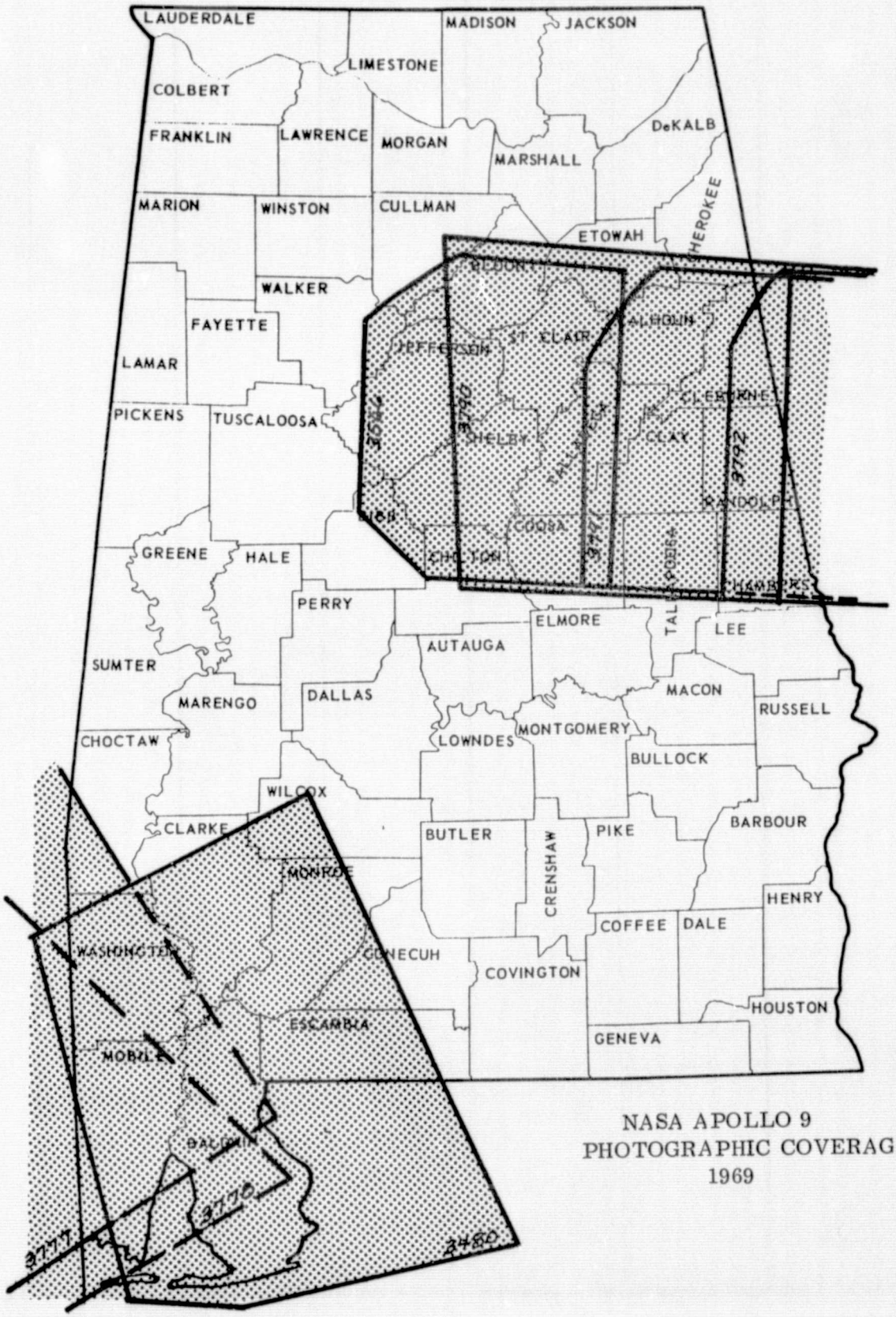



NASA SKYLAB 4
PHOTOGRAPHIC COVERAGE
FEBRUARY 1974

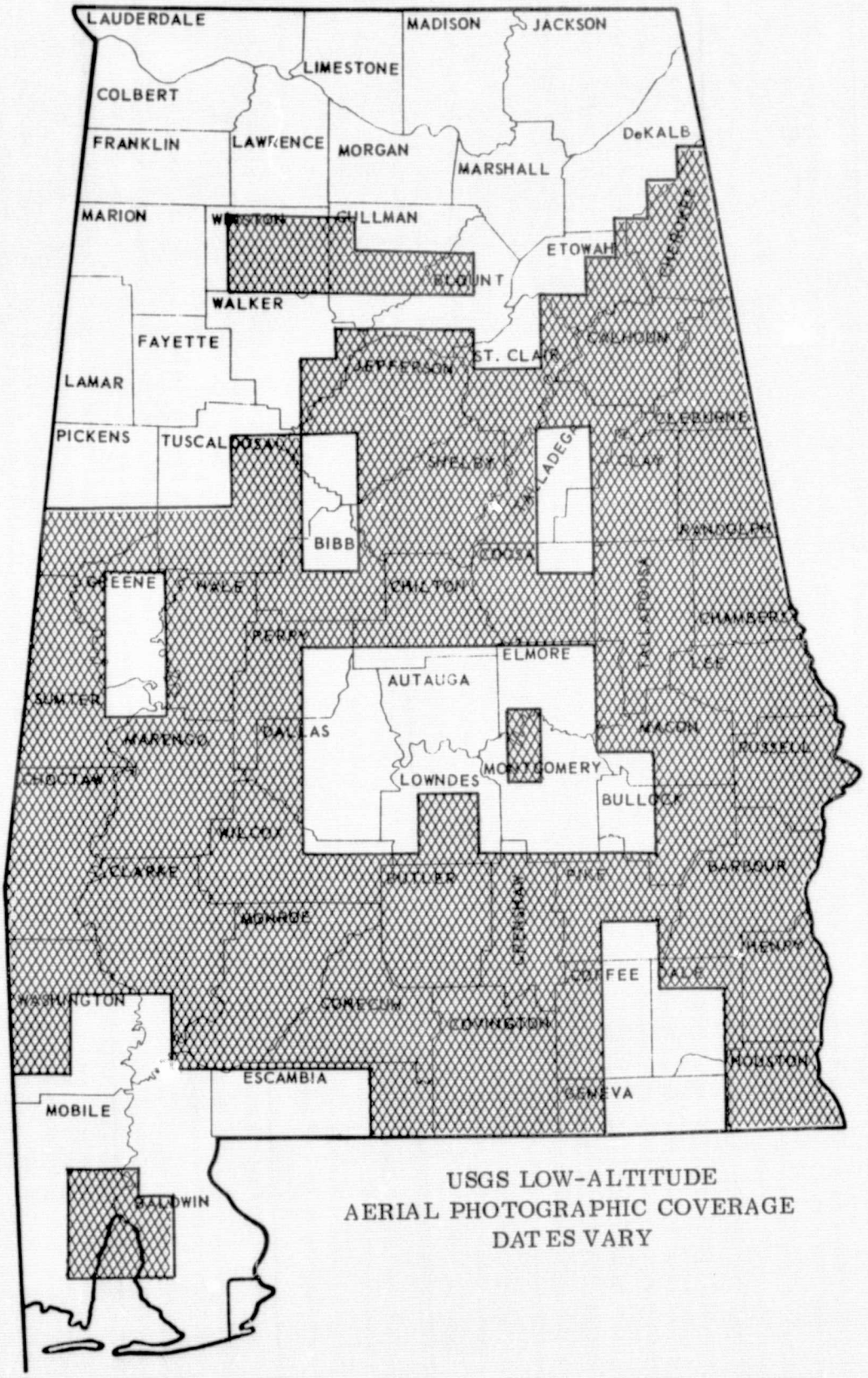
LOW AND MEDIUM
AERIAL PHOTOGRAPHY
CONTRACTED BY THE GEOLOGICAL SURVEY OF ALA.
1970 - 74



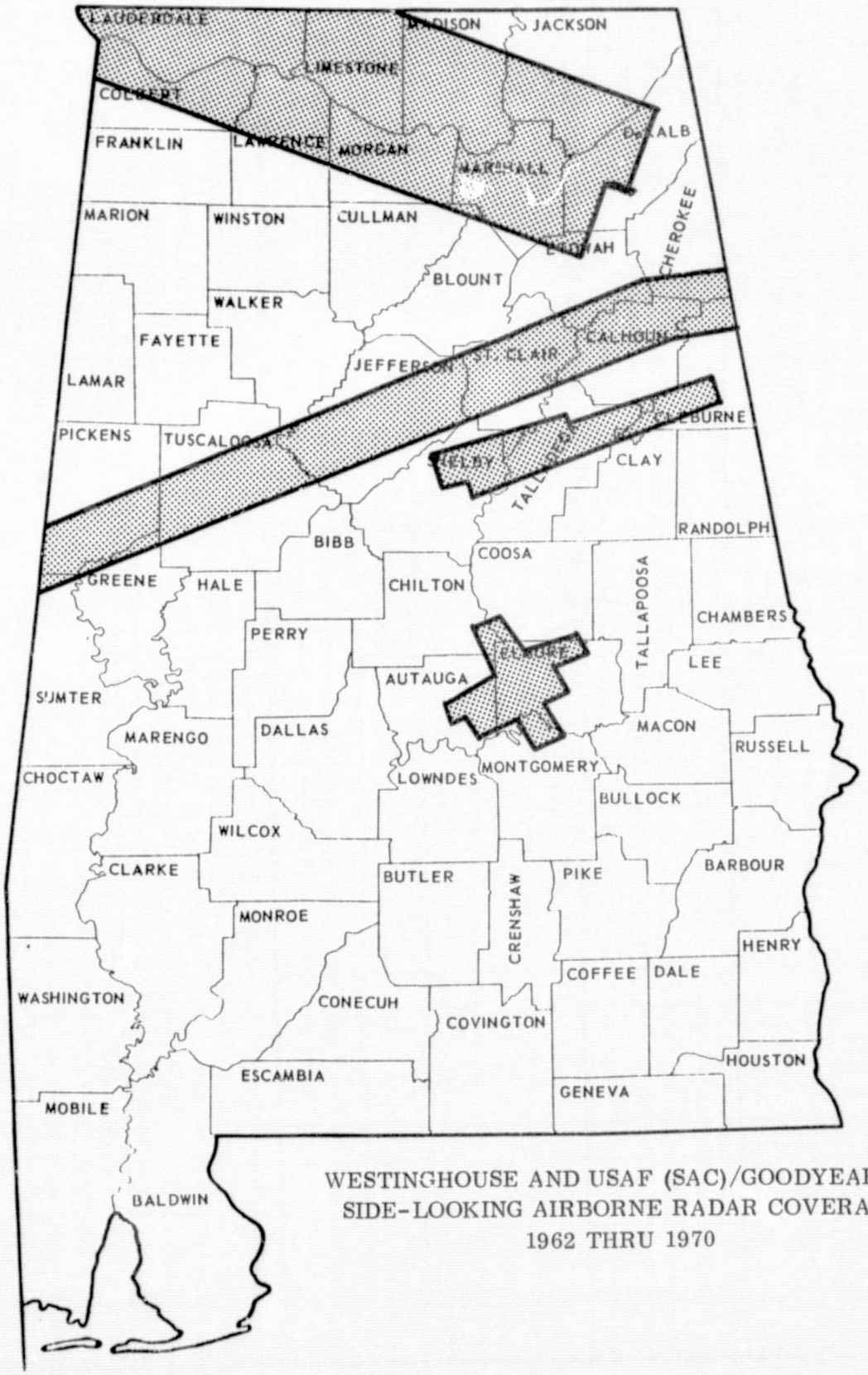

USGS PRESCOTT RESEARCH GROUP
SIDE-LOOKING AIRBORNE RADAR COVERAGE
JUNE 1974



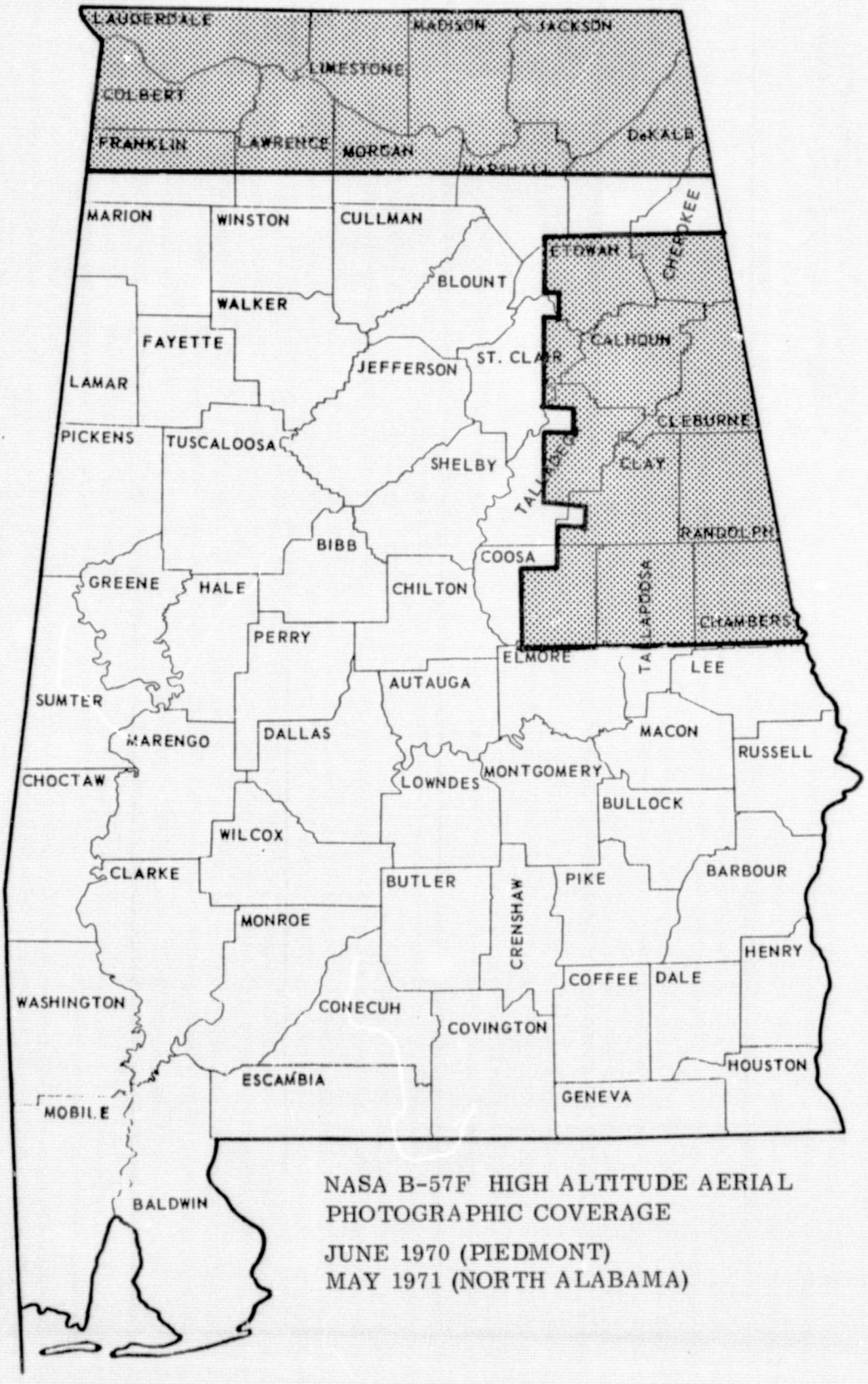

NASA APOLLO 9
PHOTOGRAPHIC COVERAGE
1969




USGS LOW-ALTITUDE
AERIAL PHOTOGRAPHIC COVERAGE
DATES VARY



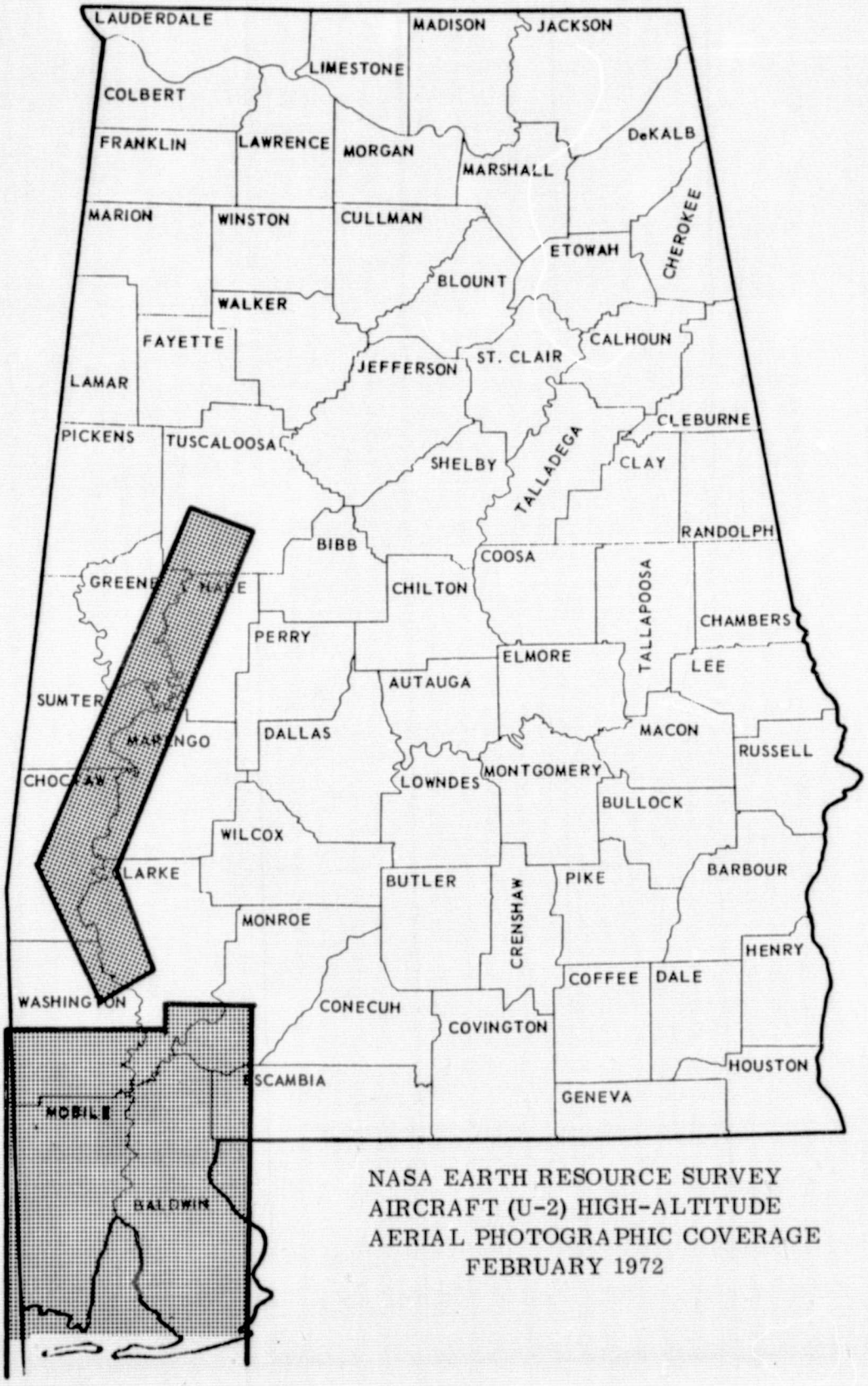

WESTINGHOUSE AND USAF (SAC)/GOODYEAR
SIDE-LOOKING AIRBORNE RADAR COVERAGE
1962 THRU 1970



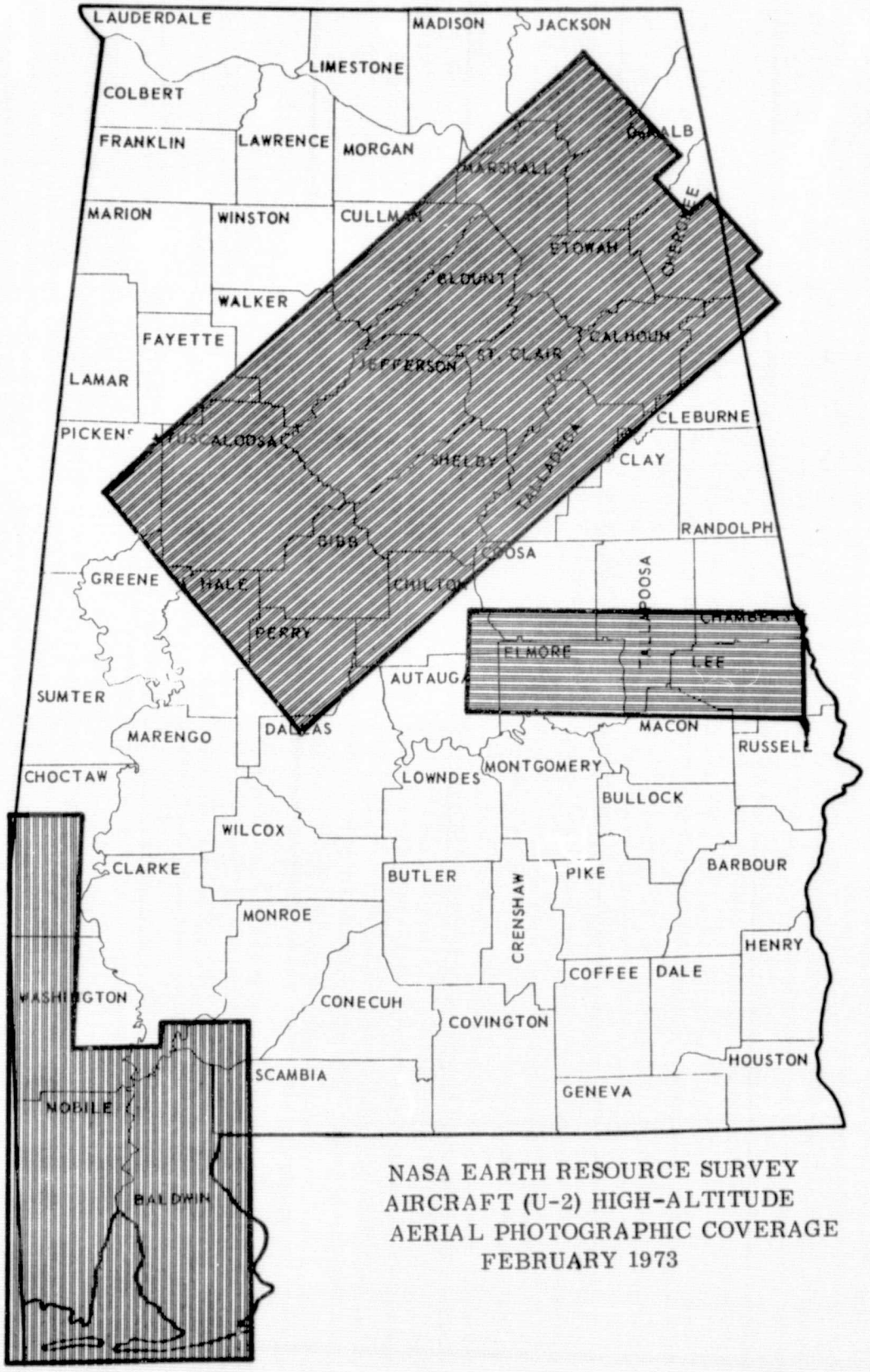

NASA B-57F HIGH ALTITUDE AERIAL PHOTOGRAPHIC COVERAGE

JUNE 1970 (PIEDMONT)
MAY 1971 (NORTH ALABAMA)

NOAA NATIONAL OCEAN SURVEY
AERIAL PHOTOGRAPHIC COVERAGE
1959 THRU 1971

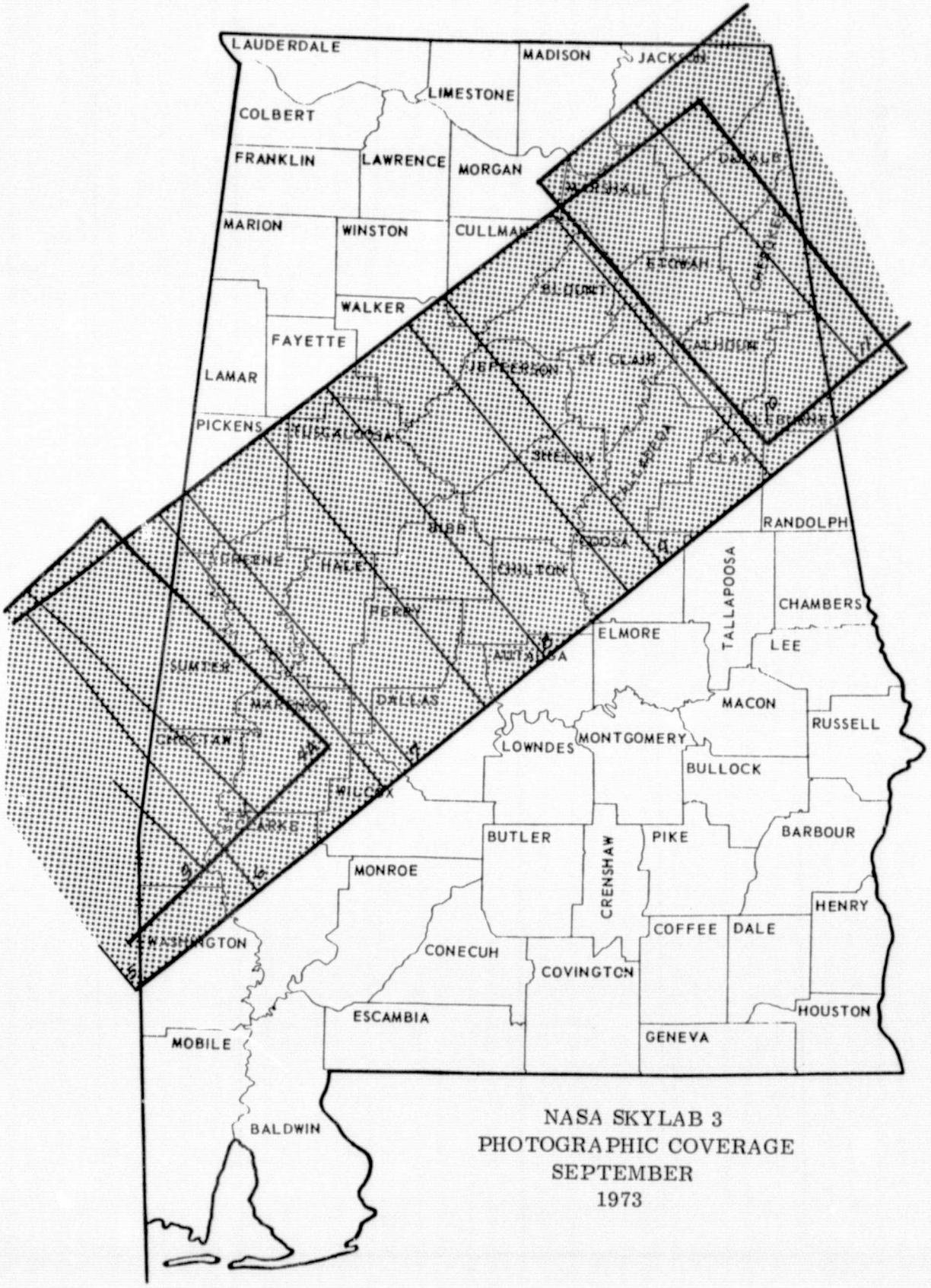



NASA EARTH RESOURCE SURVEY
AIRCRAFT (U-2) HIGH-ALTITUDE
AERIAL PHOTOGRAPHIC COVERAGE
FEBRUARY 1972

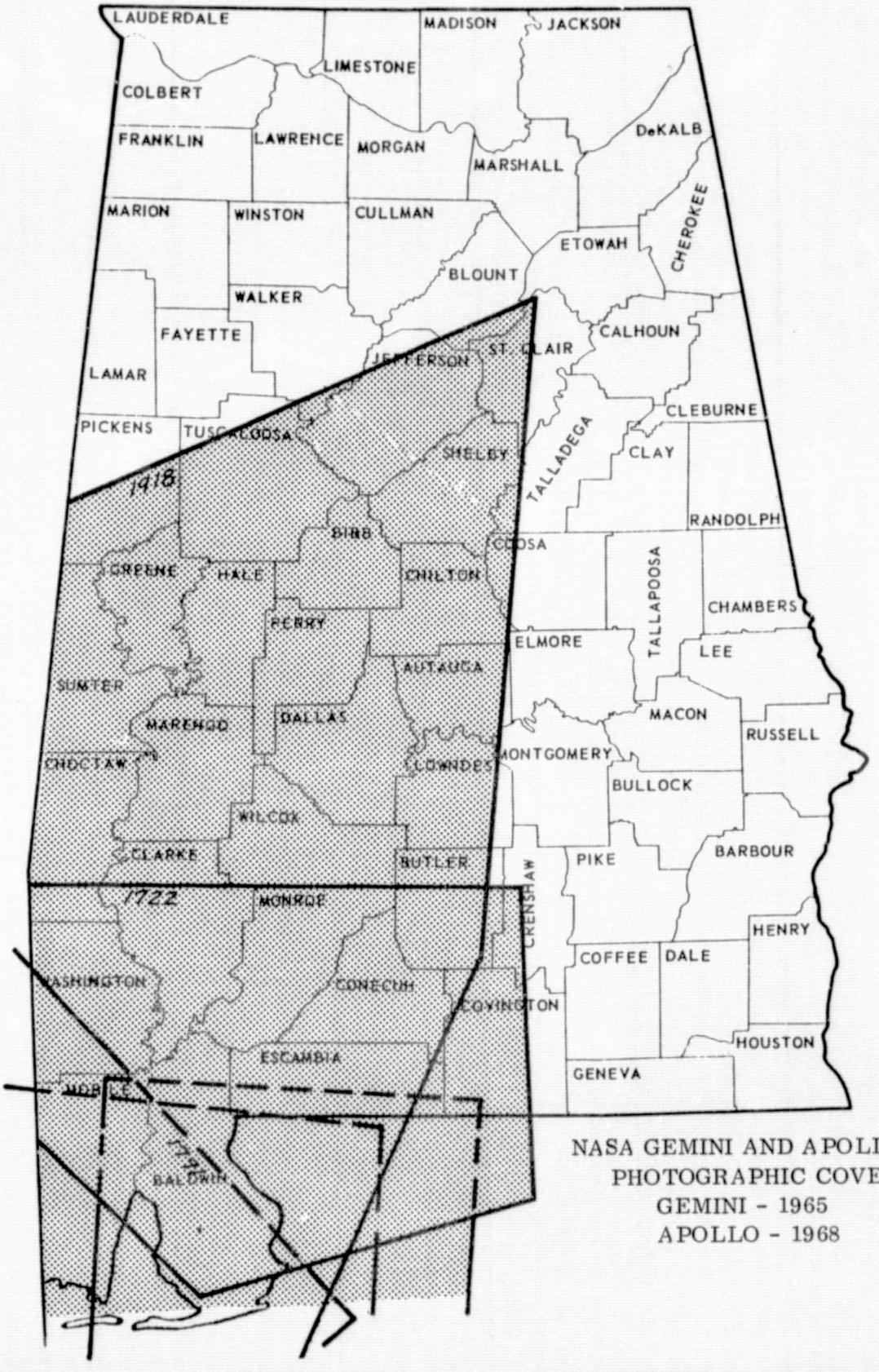



NASA EARTH RESOURCE SURVEY
AIRCRAFT (U-2) HIGH-ALTITUDE
AERIAL PHOTOGRAPHIC COVERAGE
FEBRUARY 1973

NASA B-57F HIGH-ALTITUDE
AERIAL PHOTOGRAPHIC COVERAGE
DECEMBER 1972

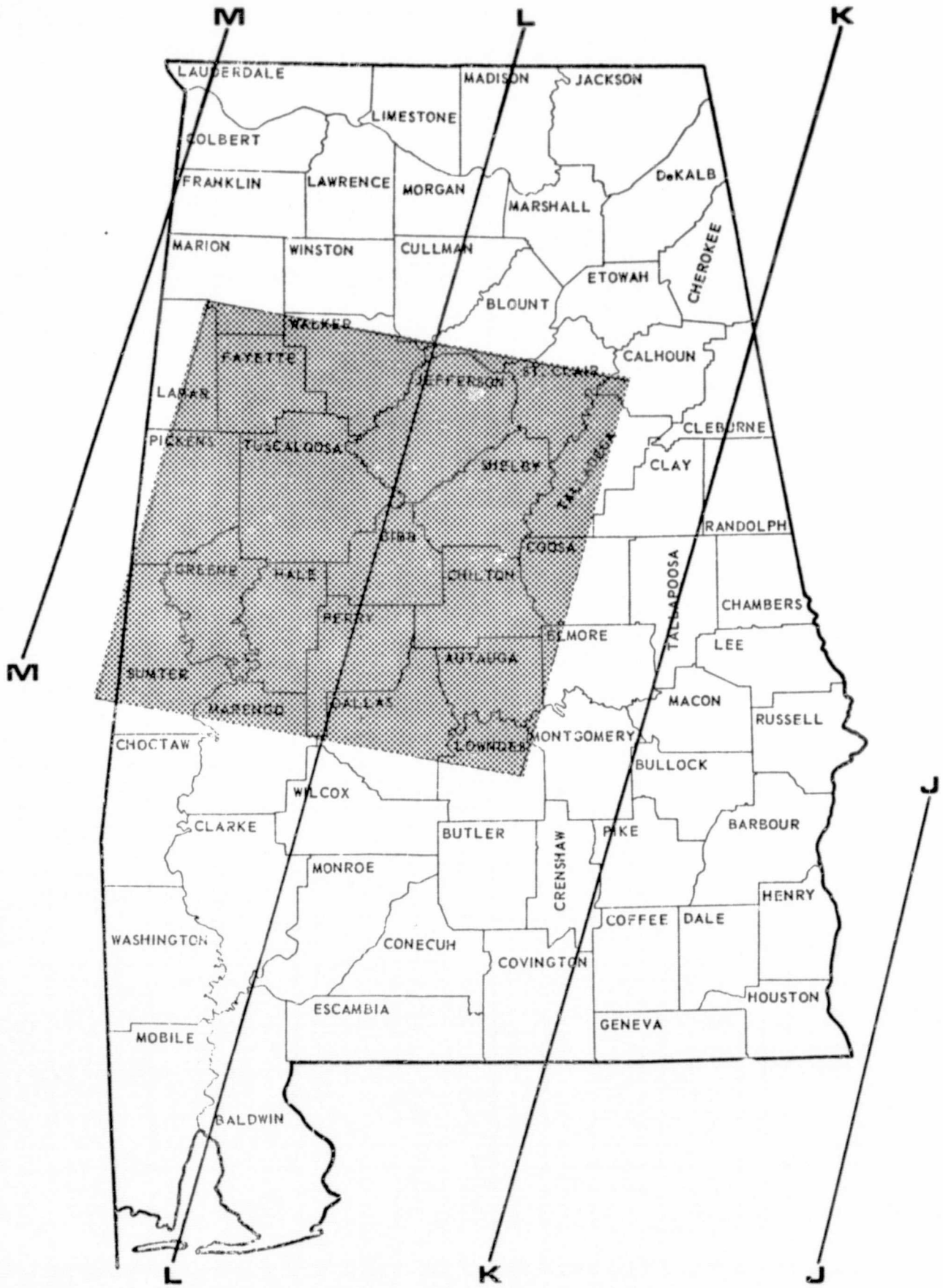



NASA SKYLAB 3
PHOTOGRAPHIC COVERAGE
SEPTEMBER
1973




NASA GEMINI AND APOLLO 7
PHOTOGRAPHIC COVERAGE
GEMINI - 1965
APOLLO - 1968

TENNESSEE VALLEY AUTHORITY
AERIAL PHOTOGRAPHIC COVERAGE
DATES VARY




LANDSAT GROUND TRACK WITH EXAMPLE OF FRAME COVERAGE